FILL

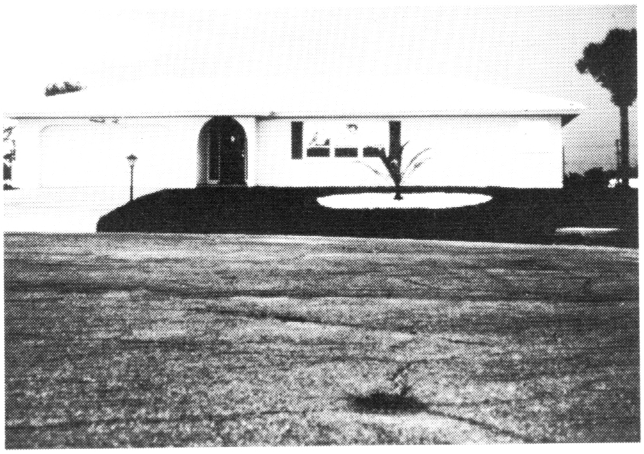


Figure 4.1. Elevation by Earth Fill

At many A-Zone sites with low-velocity flooding it is feasible to elevate structures on earth fill (Figure 4.1). Earth fill is a widely used elevation technique that with proper construction practices and materials can be the most economical means of elevating a building two or three feet above grade or in some locations even higher. Fill should not be used in V Zones, where high-velocity flooding occurs, or at sites where fill would constrict the flow of flood waters and cause increased flooding heights or velocities.

The advantages of fill (as opposed to piles or similar elevated foundations) include its generally traditional appearance, ease of access to the lowest floor (i.e., no stairs are required), the ability at many sites to connect the filled area to higher ground for emergency evacuation in a flood, the safety of building elements from deterioration caused by exposure to flood waters, and the thermal insulation the earth provides the bottom of a house. In cold climates, furthermore, spring flood water under a house elevated on piles can freeze, with the danger of uplifting the structure.

A site's topography and soil conditions may preclude use of fill. Before fill is put in place existing vegetation and any unstable topsoil must be removed. The fill should then be placed in layers not exceeding 12 inches deep, with layer compacted with pneumatic or sheepsfoot rollers or vibrating compacting equipment. For most residential applications, compaction to 95 percent of the maximum density obtainable with the Standard Proctor Test Method issued by the American Society for Testing and Materials (ASTM Standard D-698) is usually sufficient.

Provision must be made for adequate surface drainage and erosion protection. Riprapping may be required for critical exposed slopes of a fill pad.

ELEVATED FOUNDATIONS

In some situations site topography, poor soil conditions, aesthetics, or cost considerations may make it desirable to use an extended masonry or reinforced concrete foundation to elevate a house up to three or four feet above grade. Such a foundation can be bermed with earth fill to provide easy access and a conventional appearance.

Elevated foundations must be designed to withstand both hydrodynamic forces caused by velocity waters and hydrostatic forces caused by standing water. This may require added reinforcement in the walls. Where the foundation is not bermed with fill, a further design consideration would be the provision of sufficient openings in the foundation to allow the unimpeded flow of flood waters through the foundation. This can help minimize both hydrodynamic and hydrostatic forces without affecting the strength of the foundation if designed properly.

SHEAR WALLS

Shear walls, although more commonly used for motels, apartments, and other more massive structures, can also be used to elevate smaller residential structures (Figure 4.2).

A shear wall acts as a deep beam in resisting forces in the plane of the wall. Structurally, the most critical design consideration is the low resistance of a shear wall to lateral forces. Shear walls should thus be used only in areas subject to low- to moderate-velocity flooding and should be placed parallel to the expected flow of flood waters. It is important that load and impact forces be determined for the entire range of flow directions. In addition, a shear wall's vulnerability to lateral forces makes it critical that connections between the wall and the foundation elements below grade be well designed.

Figure 4.2. Elevation by Shear Walls

POSTS

Post foundations (Figures 4.3 and 4.4) use long, slender wood, concrete, or steel posts set in pre-dug holes. Posts can be round, square, or rectangular in section, though square and rectangular posts are easier to frame into than round ones. With steel posts, wide flange shapes or pipe or square tube sections are usually used.

Figure 4.3. Elevation by Posts

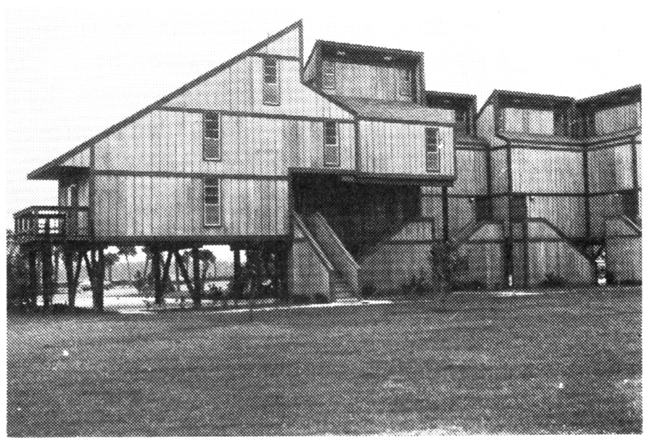


Figure 4.4. Elevation by Posts

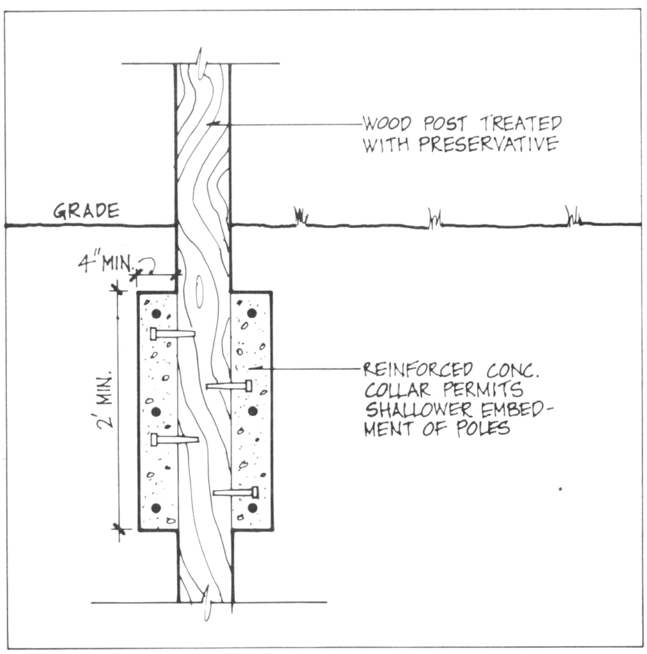


Figure 4.5. Reinforced Concrete Collar

Post foundation holes are dug by hand or machine. Posts longer than 16 feet generally require machine assistance for safe handling. Posts are generally less resistant to lateral forces from flood waters than piles or reinforced concrete masonry piers. Bearing capacity and stability of posts can be improved by pouring a concrete bearing pad at the bottom of the hole and/or pouring a concrete collar around the post after it has been partially backfilled (Figure 4.5).

Post Embedment

The depth to which posts should be embedded depends on soil conditions, including the depth of the frost line; vertical loads; lateral loads from flood waters, debris impact, and wind forces; the anticipated erosion and uplift; and the spacing and size of the posts.

The following comments and sketches indicate embedment techniques for wood posts; steel and concrete posts' requirements are similar.

Hole Depth and Post End Bearing. Wood posts are generally embedded 4 to 8 feet. Hole excavations beyond 8 feet become uneconomical, so piles are used.

If design loads are small and the allowable soil bearing capacity is adequate, i.e., dense sand or medium-stiff clay, the post can be set on undisturbed earth at the bottom of the hole (Figure 4.6).

For larger loads and/or poorer soil conditions, a concrete pad should be poured into the bottom of the hole (Figure 4.7). The pad should be approximately as thick as half its diameter, with a minimum thickness of 8 inches.

If extremely poor soil conditions are encountered it may be necessary to use concrete backfilling or piers, as discussed below, or to drive a group of piles and cast a pile cap for each post to bear on, as shown in Figure 4.8, anchoring the posts securely to the caps. This can be more expensive than other foundation types.

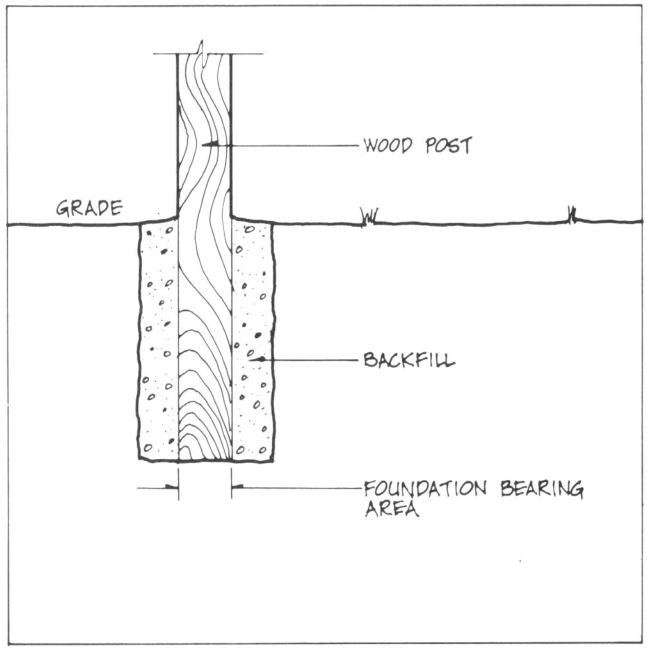


Figure 4.6. Earth Bearing

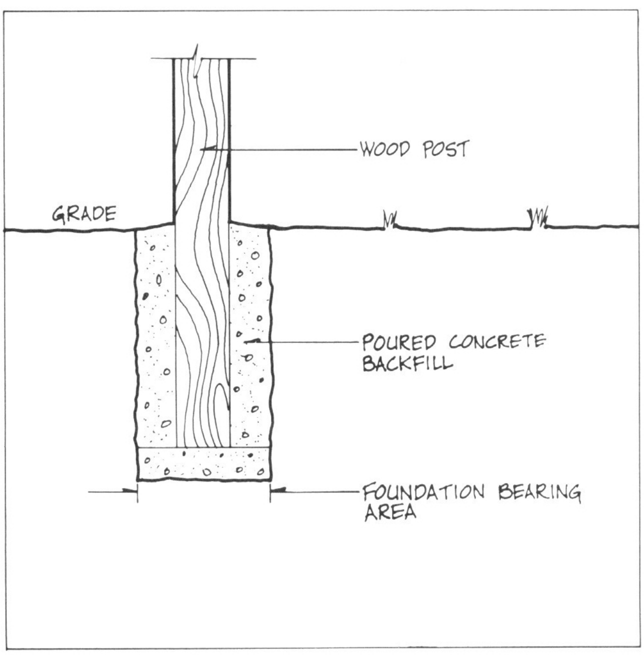


Figure 4.7. Post on Concrete Bearing Pad

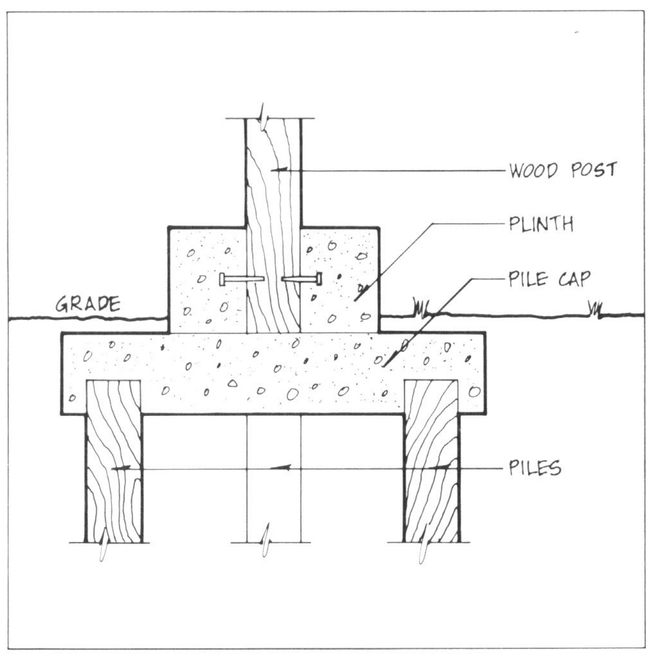


Figure 4.8. Post/Pile Foundation

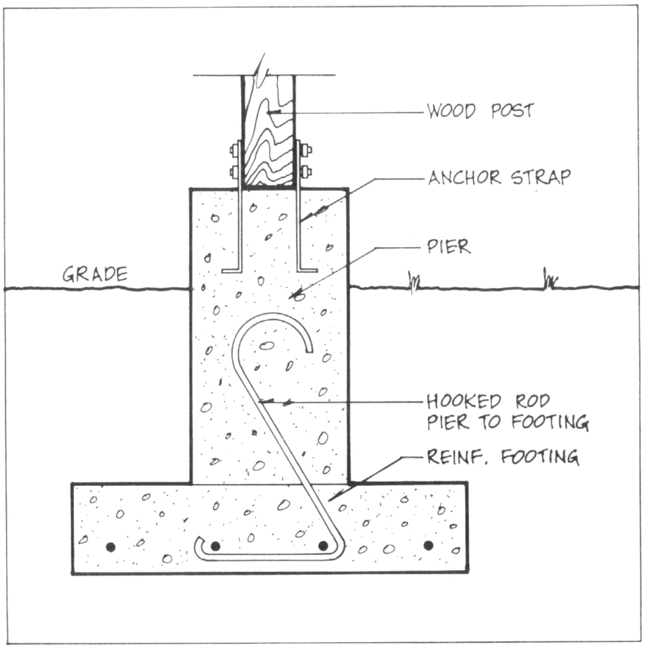


Figure 4.9. Post/Pier Foundation

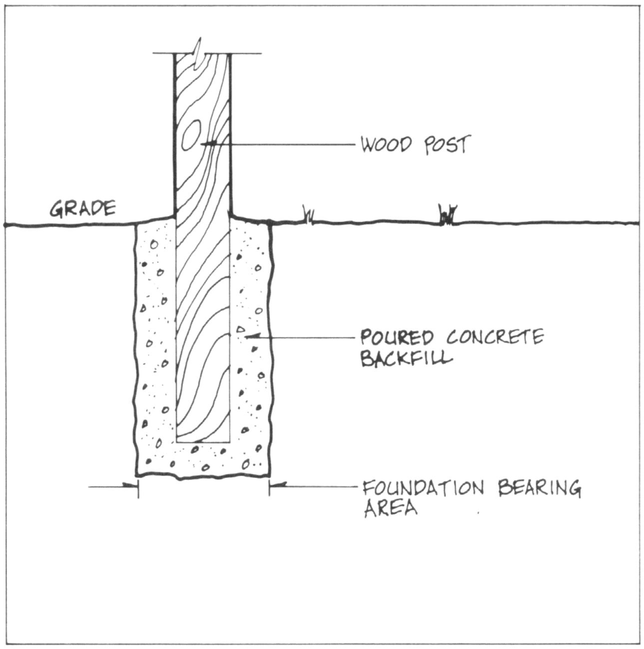


Figure 4.10. Concrete Backfill

Wood posts can also be supported entirely out of the ground on concrete piers (Figure 4.9). More thorough maintenance is possible with this approach, but additional bracing may be required for lateral stability.

Hole Size. In post construction the hole should be a minimum of 8 inches larger in diameter than the greatest dimension of a post section. This allows for alignment and backfilling.

Backfilling. Clean, well-compacted backfill is necessary to ensure a structure with good lateral stability and resistance against wind and water uplift. Common backfill materials are sand, gravel, crushed rock, pea gravel, soil cement, concrete, and earth.

Granular fills that provide good drainage are generally considered the best. Drainage around the posts at grade level should be positive to keep water from collecting and deteriorating the posts. Backfill materials should be mechanically tamped to adequately compact them. Wetting such backfill materials as earth or gravel will aid compaction.

Backfilling the hole with concrete rather than gravel or sand, as shown in Figure 4.10, adds stability to the structure and increases the bearing area. Shallower embedment may be possible with this method.

Soil cement is an economical alternative to concrete and attains strength nearly equal to it. Soil cement is made by mixing the earth removed from the dug hole with cement in a ratio of 1 part cement to 5 parts earth (plus water as directed by the manufacturer). To achieve the best results all organic matter should be removed from the earth, and it should be sifted to remove all particles larger than 1 inch.

Anchorage

Lateral forces and flood forces are less likely to overturn or uplift posts if the posts are anchored to a foundation. Two ways to anchor posts are to embed them in concrete or to fasten them to metal straps, angles, plates, etc., that are themselves anchored in concrete footings, piers, or pile caps.

Figure 4.11 shows one method of anchoring wood posts in concrete. Large (5/8- to 3/4-inch in diameter) spikes or lag bolts are driven into the post around its base. The post is placed into the hole and secured to bracing restraints to prevent movement through the footing while the concrete sets.

The metal fastening method of anchorage can be used above or below ground. Figure 4.12 shows a square wood post lag bolted to a metal shoe that is anchored in a pier. In Figure 4.13, heavy gauge galvanized steel straps are used to anchor the wood post to a concrete pad.

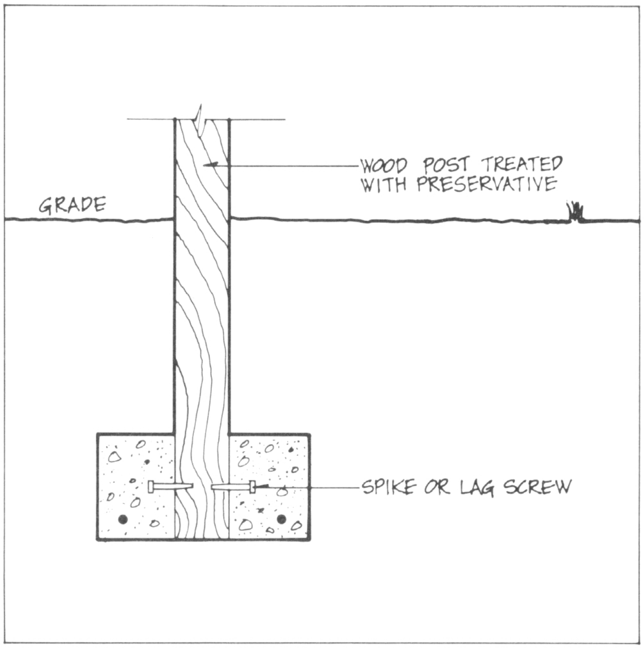


Figure 4.11. Spike Anchorage of Post

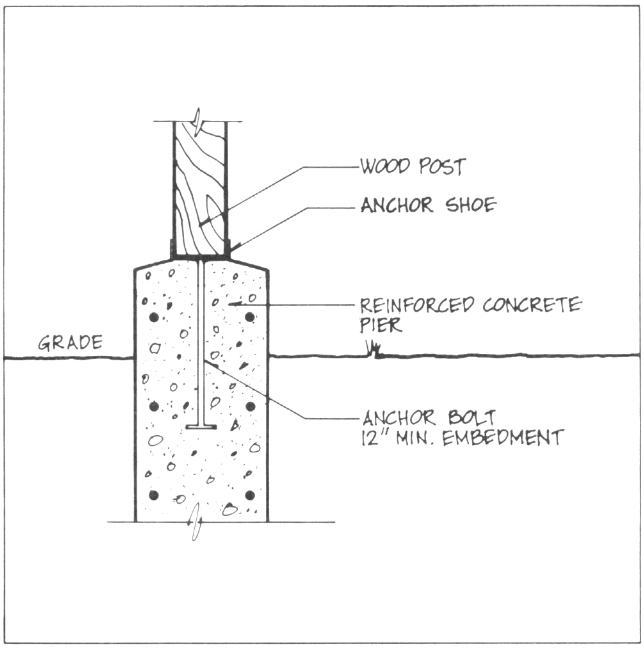


Figure 4.12. Metal Angle Anchorage Detail

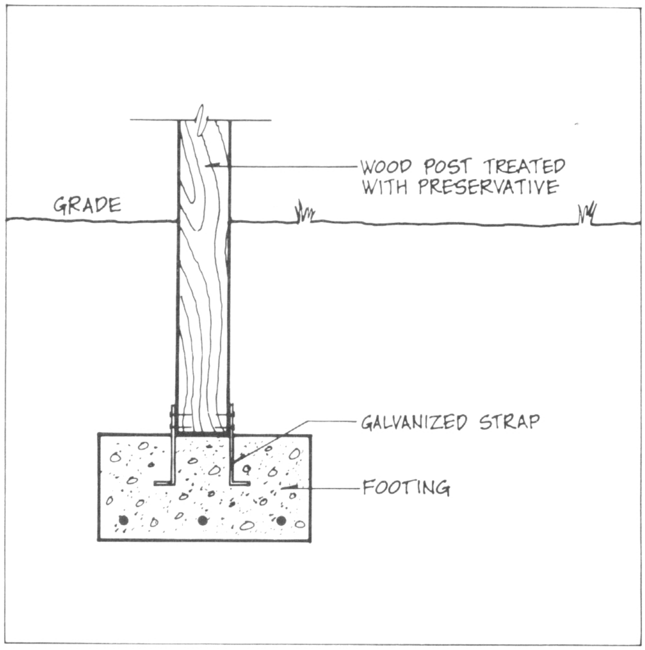


Figure 4.13. Galvanized Strap Anchorage Detail

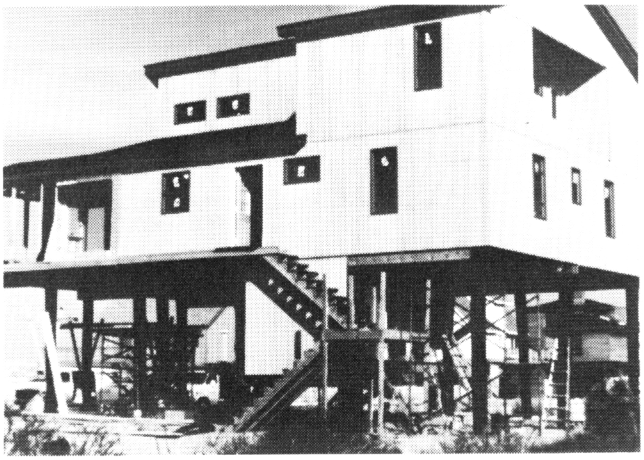


Figure 4.14. Pile Foundations

PILES

Pile foundations (Figure 4.14) use long, slender wood, steel, or reinforced concrete piles that are driven or jetted into the ground. Vertical loads can be carried by driving piles to a load-bearing layer, such as rock (end-bearing piles), or by driving the piles deep enough into the earth to develop enough friction between the surface of the piles and the surrounding soil to carry the load (friction piles). Friction piles, which can also have an end-bearing component, are most often used for typical light residential loads.

Piles are structurally stronger than posts and are therefore more suitable for the extreme wind and water forces and erosion in coastal V Zones. Piles in V Zones should be designed in accordance with *Design and Construction Manual for Residential Buildings in Coastal High Hazard Areas*, cited in the Preface.

Pile Materials

Piles can be concrete, steel, or wood. In coastal areas, where steel piles are not desirable because of corrosion problems, concrete piles can be particularly good when combined with precast concrete floor beams; such structural systems can be efficient, economical, and flood resistant. Concrete piles can be particularly suitable for buildings of more than two stories.

The vulnerabilities of different pile materials to environmental conditions are discussed in the materials section later in this manual.

Wood piles are probably the most widely used foundation for elevated residential structures. In some locations, square timbers are preferred over round piles because of cost, availability, and ease of framing and connecting the structural floor beams to the piles. The most popular suitable sizes (in inches) are 10 x 10 and 8 x 8 square roughsawn members.

Round timber piles are also frequently used. Generally, round piles are available in longer lengths than square timbers, and for lengths greater than about 25 feet round piles are frequently the only piles available. Round piles are often preferred because they can provide greater cross-sectional area, peripheral area, and stiffness than square sections, particularly the 8 x 8 timbers. A minimum tip diameter of about 8 inches, and a butt or top diameter (at the floor beam level) of about 11 inches or more are recommended for round piles.

Pile Embedment Methods

A major consideration in the effectiveness of pile foundations is the method of inserting piles into the ground. This can determine the amount of the piles' load resistance. It is best to use a pile driver, which uses leads to hold the pile in position while a single- or double-acting hammer (delivering about 10,000 to 15,000 foot-pounds of energy) drives piles into the ground. A pile driver should be used for precast concrete piles and steel piles.

The pile driver method, while cost-effective for a development with a number of houses being constructed at one time, can be expensive for a single residence. An economical alternative, the drop hammer, consists of a heavy weight (several hundred pounds) that is raised by a cable attached to a power-driven winch. The weight is then dropped 5 to 15 feet onto the end of the pile. Drop hammers must be used with care because they can damage wood piles.

Disadvantages of pile driving include difficulties with alignment and with setting a driver up on uneven terrain. The advantage is that the driving operation forces soil outward from around the pile, compacting the soil and causing increased friction along the sides of the pile, which provides greater pile load resistance. A much less desirable but frequently used method of inserting piles into sandy coastal soil is "jetting." Jetting involves passing a high pressure stream of water through a pipe advanced alongside the pile. The water blows a hole in the sand into which the pile is continuously pushed or dropped until the required depth is reached. Sand is then tamped into the cavity around the pile and the end of the pile pounded with the heaviest sledge hammer or other weight available. Unfortunately, jetting loosens not only the soil around the pile but also the soil below the tip. Therefore, only low end and side friction load capacity is attained, and the piles must be inserted deeper into the ground than if they were driven.

If the soil is sufficiently clayey or silty, a hole can be excavated by an auger or other means. The hole will stay open long enough to drop in a pile. Some sands have enough clay or silt to also permit the digging of a hole. Then sand or pea gravel can be poured and tamped into the cavity around the pile. Again, this does not provide as good load resistance as driving the pile into the ground, and longer piles are necessary. With short wood piles, some final driving with a sledge hammer can be helpful.

Soil Conditions and Embedment Depth

Local building codes often specify the required embedment depths of piles, e.g., to at least 6 feet below grade. Such codes often do not take into account the conditions at specific sites; a soils engineer should be consulted in doubtful situations. In addition, *Design and Construction Manual for Residential Buildings in Coastal High Hazard Areas*, cited in the Preface, provides useful information on this subject.

The required depth of pile embedment depends primarily on the number of piles used, the size and weight of the structure, and the type of soil at the building site. The pile depth is also influenced by the lateral forces from flooding and wind and debris impact, the manner in which the piles are inserted into the soil, and the need to allow for erosion of the soil that supports the piles.

In riverine environments the soil types and the anchorage provided by the frictional force of the soil against the sides of the pile vary widely. Sand is the dominant soil component in most coastal areas, but in some areas there may be

Figure 4.15. Pier Foundations

an underlying layer of several feet of clay. Generally, clay soils provide greater load-bearing capacity with less penetration than sandy soils.

Clay soils are also less susceptible to erosion. The depth of erosion of sandy soils caused by wave action is virtually impossible to predict. Piles supporting residential structures on sandy coastal shorelines should penetrate the ground deeply enough to provide resistance to wind and water loads even after extensive erosion has occurred.

Posts are often backfilled partly with concrete to improve their resistance to lateral forces. The same technique can be used with piles. After piles are driven, the area around each pile is dug out and a thick concrete collar is poured, extending several feet below grade. Such collars provide protection from minor erosion, add some deadweight to the structure, and increase piles' pull-out resistance.

PIERS

Pier foundations (Figure 4.15) are suitable in areas away from a river or coastline where flood waters move with low velocity and erosion will be minimal.

Pier foundations use brick, concrete masonry blocks, or poured-in-place concrete to elevate structures. To resist horizontal wind and water forces, piers should rest on substantial spread footings or a grade beam, with reinforcing steel rods extending from these elements through the full height of the piers to resist tensile stresses.

Pier Materials

The vulnerability of pier materials to environmental conditions is discussed in the materials section later in this manual.

Brick and Concrete Masonry Piers

Brick piers and concrete masonry piers should be a minimum of 12" x 12" and reinforced with steel rods (Figures 4.16 and 4.17). Hollow concrete masonry units should be filled with concrete.

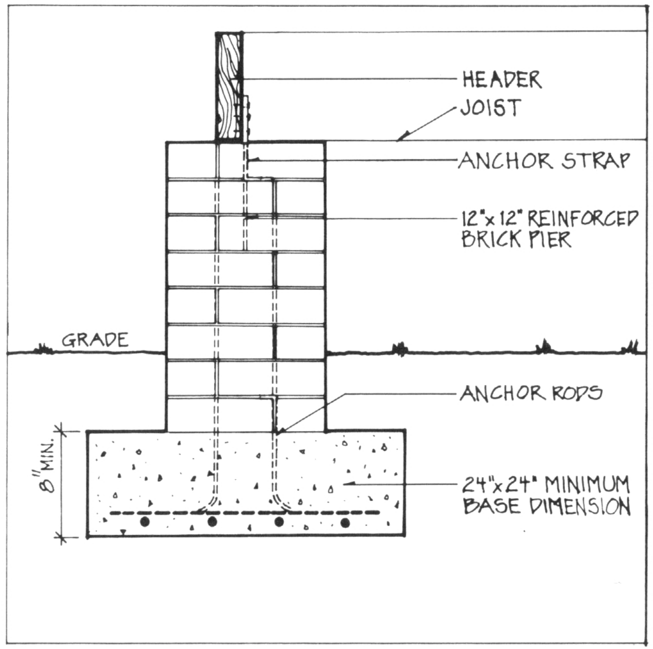


Figure 4.16. Reinforced Brick Pier

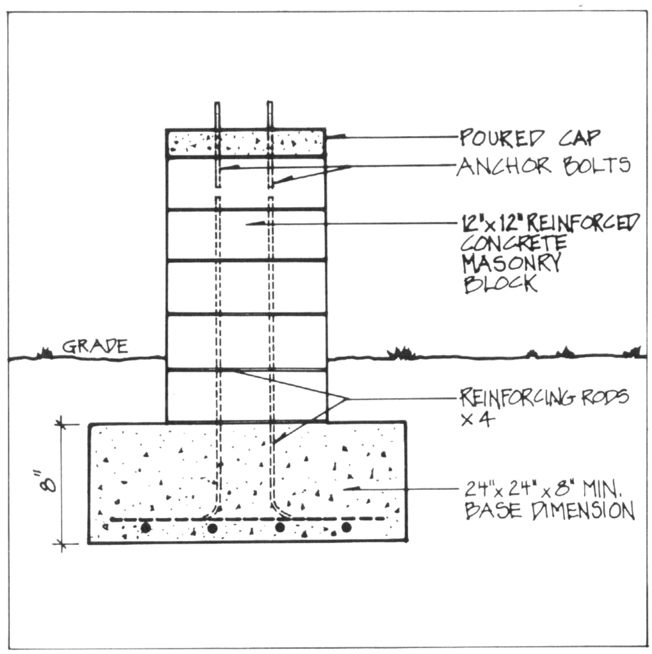


Figure 4.17. Reinforced Concrete Masonry Pier

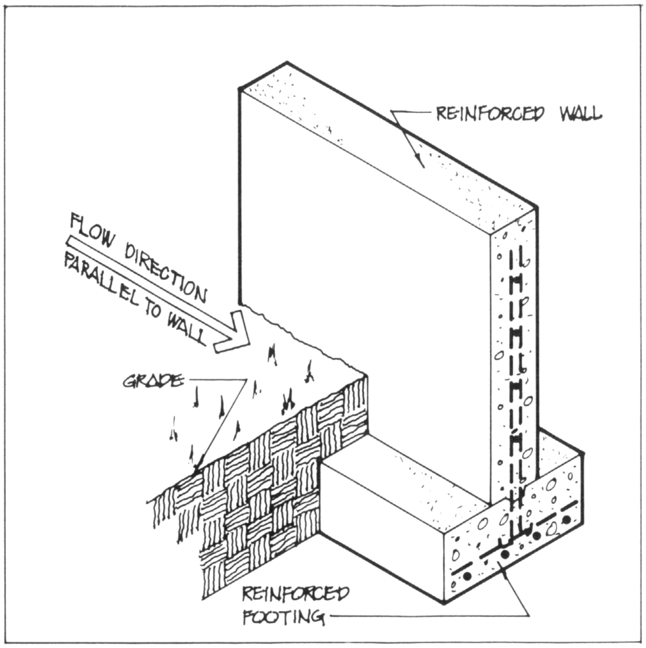


Figure 4.18. Wall Foundation

Reinforced brick piers can be used to elevate structures 1½ to 6 feet off the ground. Concrete masonry piers are effective for elevations of 1½ to 8 feet. In general, the height of reinforced concrete masonry piers should be limited to a maximum of ten times their least dimension. Square piers are preferable. If the piers are rectangular the longer dimension should not exceed the shorter dimension by more than 50 percent.

According to the National Concrete Masonry Association, the allowable working stresses for concrete masonry piers are the same as those for the design of concrete masonry walls. The pier masonry should be laid with type M or S mortar. The association also recommends that the spacing between piers supporting floor joists not exceed 8 feet in the direction perpendicular to the joists, nor 12 feet in the direction parallel to joists.

These minimum requirements apply whether the pier is free standing or laterally braced. In cases where exceptionally large loading conditions may exist, the pier cross-section should be increased and/or additional reinforcement added. A larger cross-section can be obtained by using piers several feet in length. The long dimension should be placed parallel to anticipated flood flow, as in Figure 4.18. In coastal areas, however, flood forces may come in at an angle, loading such a pier adversely, so alternatives should be considered.

Poured-in-Place Concrete Piers

Poured-in-place concrete piers are essentially reinforced concrete columns. They are cast in forms set in machine- or hand-dug holes. The holes can be widened or belled at the base to form a footing integral with the pier, or, as shown in Figure 4.19, a separate footing can be poured. If soil conditions are appropriate the footing can be eliminated and loads left to end bearing and friction between the soil and pier (Figure 4.20). Poured-in-place piers of the latter type can be particularly effective for larger homes or developments of single-family homes and townhouses.

Poured-in-place concrete piers can be used to elevate a structure 1½ to 12 feet or more. The dimensions, reinforcement, and spacing of concrete piers depend on the type of building framing used and on building and environmental loads; structural analysis is required.

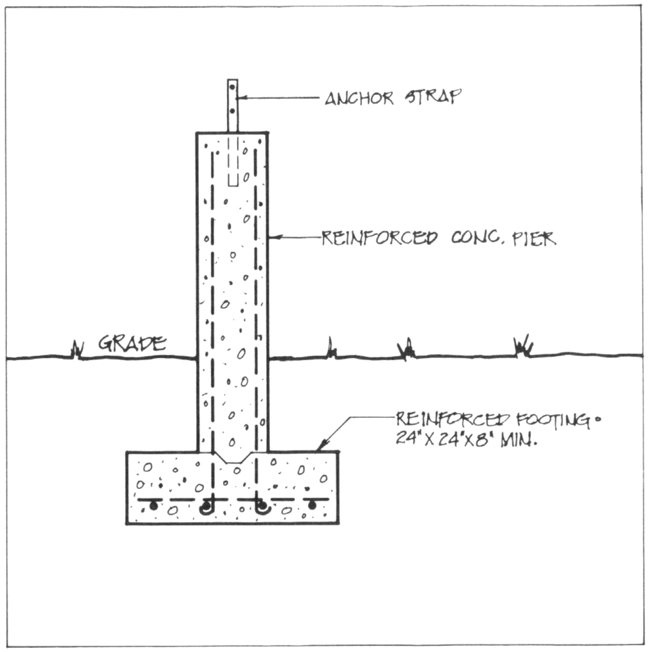


Figure 4.19. Reinforced Concrete Pier

Pier Footings

Pier footing sizes are a direct function of soil bearing capacity and loading, and can be computed on the basis of local codes. Depth of pier footings depends on local frost penetration levels and expected flooding, wind, and erosion levels. Footings in areas with soils of high volume change potential can be unstable, and should be designed with the guidance of a soils engineer.

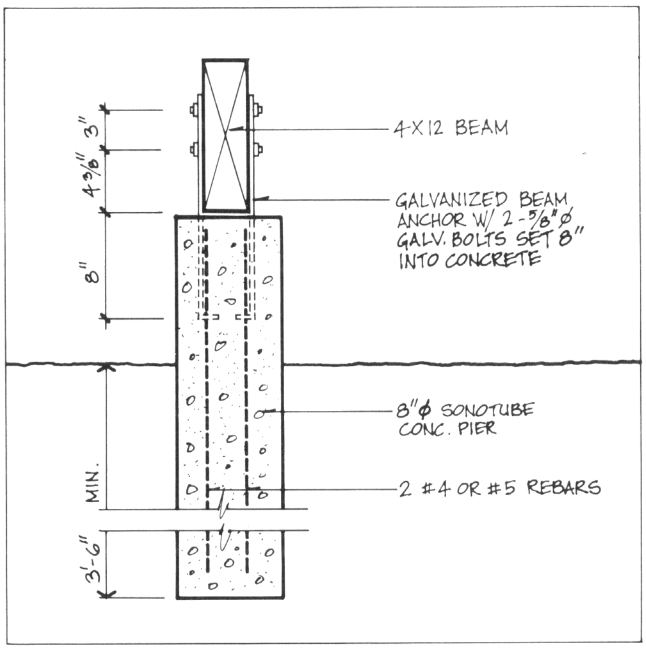


Figure 4.20. Drilled Pier Foundation

BRACING ELEVATED FOUNDATIONS

Elevated foundation elements must be braced when analysis indicates that their size, number, spacing, and embedment will not be sufficient to resist lateral forces. Even in areas where low-velocity flooding is anticipated, bracing can provide added assurance that the structure will withstand the impact of floating debris or greater-than-expected flood or storm forces. Although bracing placed underneath a structure may be struck by floating debris, the effects of this on a structure's survivability are generally outweighed by bracing's beneficial effects.

Knee Braces and Diagonal Bracing

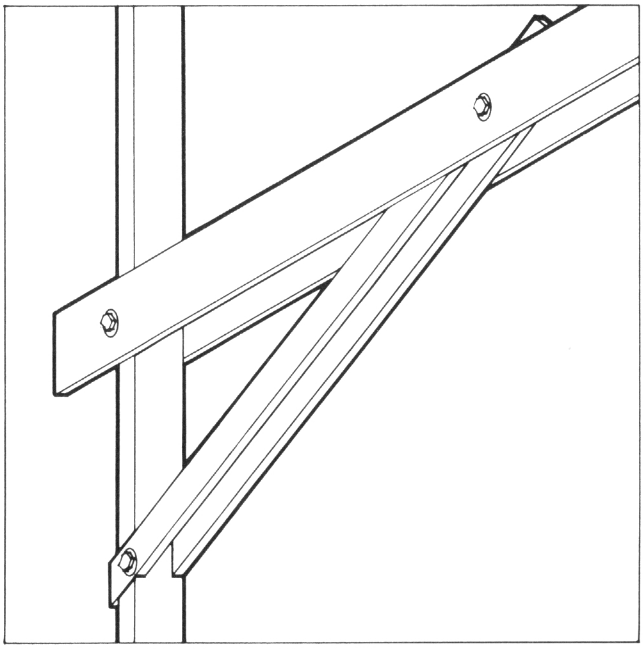


Figure 4.21. Knee Brace

Knee braces (Figure 4.21) and diagonal bracing can be effective in providing lateral strength. Lumber more than 2 inches thick is usually recommended. Bolts are preferred over nails for connecting bracing, because of bolts' greater resistance to pullout forces. Knee bracing is usually bolted between the floor joist and post or pile.

Diagonal bracing (Figures 4.22 and 4.23) is bolted at the base of one post or pile and fastened in a like manner to the adjacent post or pile just below the floor beams. Although diagonal bracing is more likely than knee bracing to be struck by floating debris, this is generally outweighed by the greater lateral stability with diagonal bracing, especially in higher elevated structures. Steel rods can sometimes be used to diagonally brace wood posts or piles. The rods are fitted through drilled holes flooded with wood preservative and fastened with nuts and cast beveled washers. Welded connections or drill holes can be used to provide rod bracing in steel post or pile foundations. Such rods are usually 5/8 to 3/4 inches in diameter. Steel diagonal ties, while effective, require considerably more monitoring and maintenance than wood because of steel's susceptibility to corrosion.

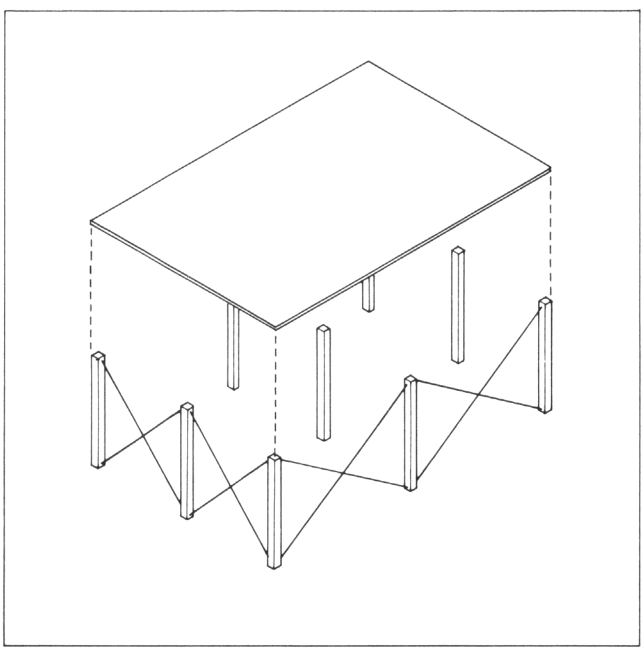


Figure 4.22. Diagonal Bracing

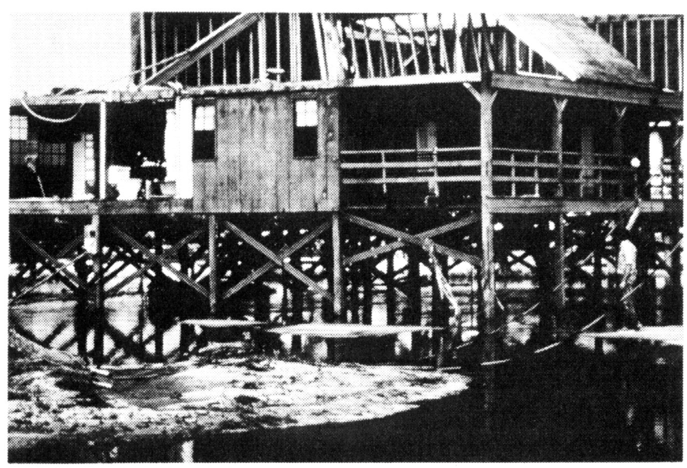


Figure 4.23. Diagonal Bracing

Shear Walls and Floor Diaphragms

In areas with low- to moderate-velocity flooding, shear walls placed parallel to the flow of flood waters and firmly attached to piles or posts can help brace them (Figure 4.24).

With wood shear walls, the plywood sizes, the strength of wall edges, and the walls' anchorage are all important to effective bracing.

A shear wall can be used in conjunction with a floor diaphragm (Figure 4.25) to transfer horizontal forces or reduce embedment depth when, for example, solid rock is reached when digging foundation holes. A floor diaphragm can be used with either pole frame or platform construction. Floor diaphragms usually call for 1/2- or 3/4-inch plywood.

The severe lateral forces encountered in coastal V Zones can require the use of trusses, grade beams, or slabs to provide adequate support. These are discussed in *Design and Construction Manual for Residential Buildings in Coastal High Hazard Areas*, cited in the Preface.

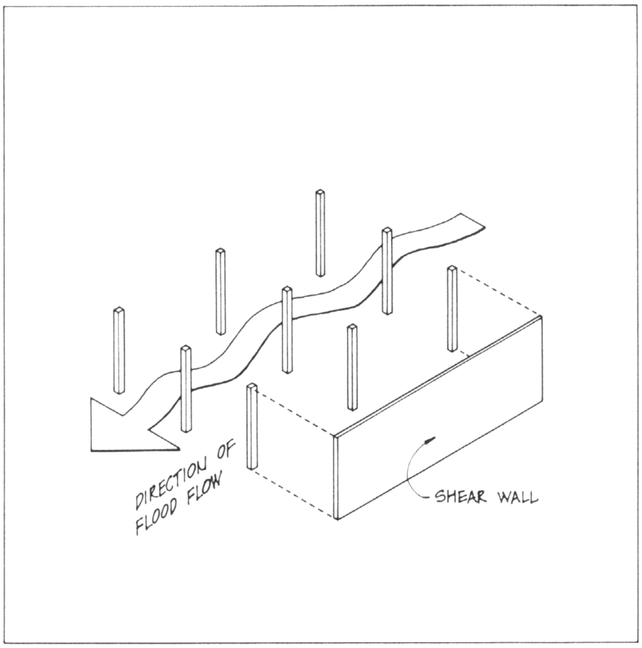


Figure 4.24. Shear Wall Bracing

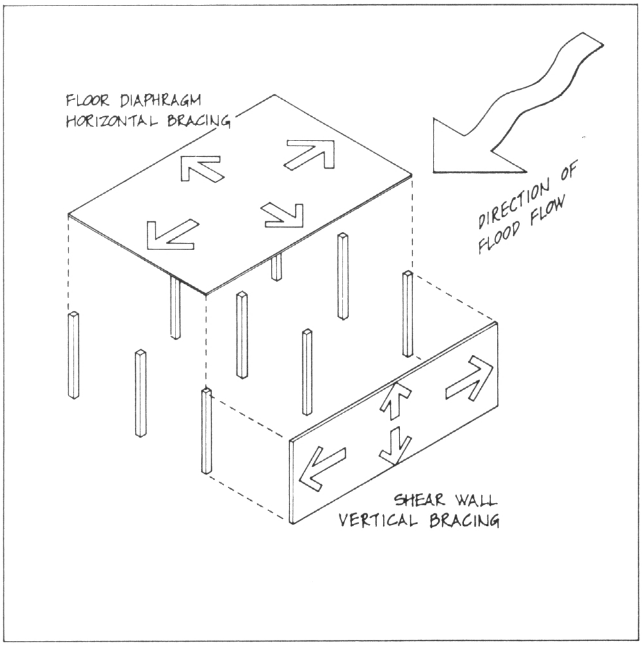


Figure 4.25. Floor Diaphragm Bracing

Framing Construction and Connections

The framing construction and framing connections in an elevated home can be critical to its ability to withstand flood forces with minimal damage. Construction in most non-flood areas must support loads imposed by the weight of the building materials (dead load), weight of people and objects (live load), and modest loads imposed by wind. Under normal conditions and with typical methods of framing construction and framing attachment, these loads act downward through gravity to hold the building's structure together.

However, these loads represent only a portion of the loads imposed on any structural system in flood-prone areas, particularly in coastal V Zones. Additional forces can be applied to these structures by floating debris, velocity flooding, extreme winds, and wave action. These buildings' structural system must be capable of withstanding these loads and still support the structure and its contents.

Coastal V Zones are virtually certain to be subjected to the extremes of these forces, and homes there should be designed in accordance with *Design and Construction Manual for Residential Buildings in Coastal High Hazard Areas*, cited in the Preface.

Even in riverine and coastal A Zones, however, prudence suggests that homes be built with a margin of safety beyond that needed in non-flood areas. Consideration should also be given to the possibility that flood forces may be greater than those anticipated on the basis of past floods or hydrologic analyses. Coastal areas pose the additional danger that shifting dunes or other storm-induced topographic changes can transform relatively safe A Zones into V Zones, which experience the full force of ocean storms.

Measures to provide a home with an extra margin of safety to resist these forces are not expensive, e.g., having floor joists 12 inches on center instead of 16 inches on center, or using deformed shank or annular ring nails because of their greater holding ability. Nor are the needed craftsmanship and anchorage methods uncommon to the carpentry trade. Simple nailing, for example, especially end or

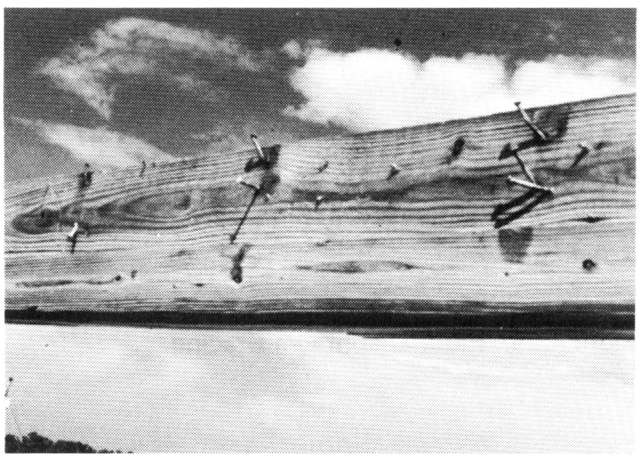


Figure 4.26. Toe Nailing Provides Limited Pull-Out Resistance

toe nailing, provides little resistance to flood forces, partially because of the tendency to split the wood in the toe-nailed member (Figure 4.26). Bolts, lag bolts, or nails in metal anchors at right angles to the direction of force (Figure 4.27) are well-known methods of increasing structural strength.

The following paragraphs discuss prudent framing construction and connections practice from the bottom up, starting with the foundation-to-floor-beam connections and floor beam construction and ending with wall-to-roof connections.

FOUNDATION-TO-FLOOR-BEAM CONNECTIONS

Post and Pile Foundations

The connection of a post or pile foundation to the framing system of a structure is influenced by the method of framing used and the cross-sectional shape of the post or pile.

Framing Methods. Two different methods for framing into post or pile foundations are in common use today: platform construction and pole frame construction.

Platform construction entails simply cutting posts or piles off at the desired elevation and framing them with beams to support floor joists and deck. The platform thus formed serves as the first habitable floor and construction platform for any type of conventional framing structure desired (Figure 4.28).

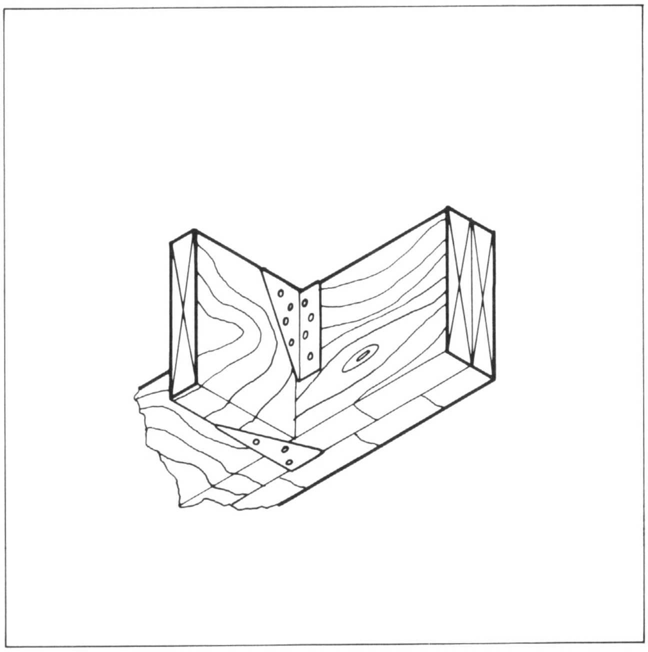


Figure 4.27. Metal Framing Anchors

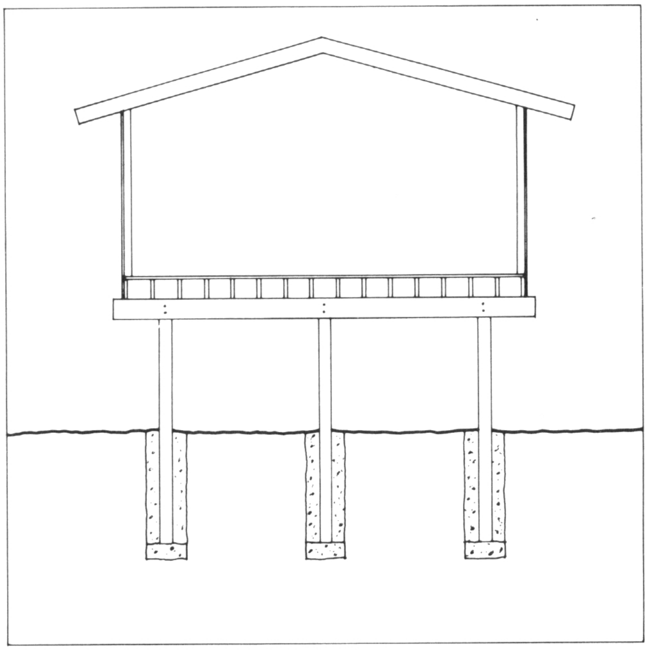


Figure 4.28. Platform Construction

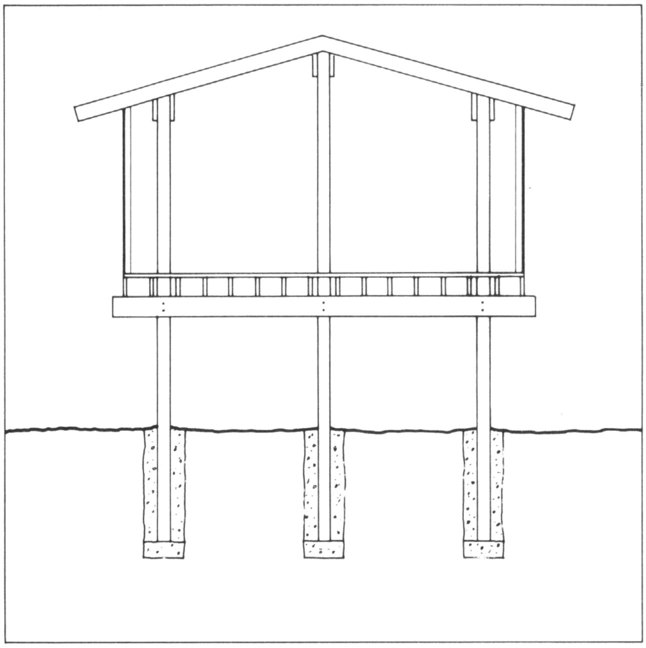


Figure 4.29. Pole Frame Construction

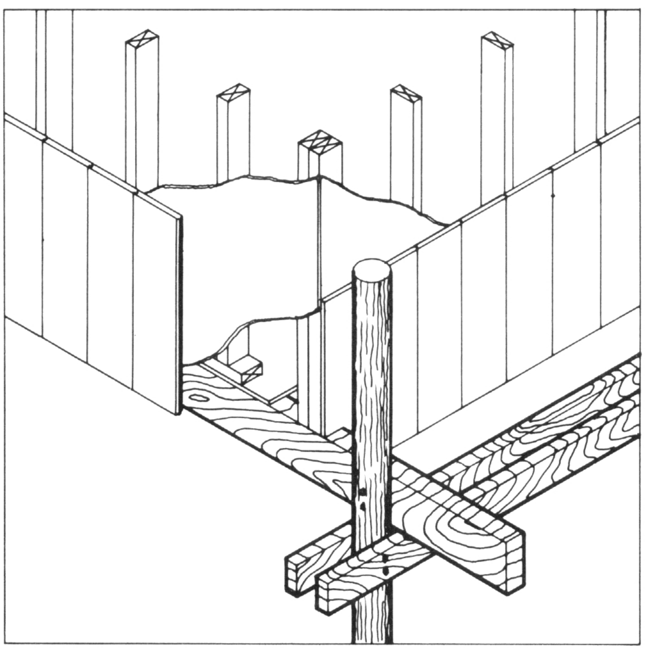


Figure 4.30. Exterior Pole Framing

In what is termed pole frame construction, the posts or piles are extended up to or through the roof, with beams framing around them as supports for floor joists and roof rafters (Figure 4.29). This method securely ties the entire structure together and is excellent for sites where lateral forces may be strong.

A basic problem with piles is their alignment. Posts can be plumbed and aligned easily before they are backfilled, but piles must be jacked and pulled into position. This can be more of a problem with pole framing than platform construction. A solution is to locate piles either on the interior or exterior of a structure, not in the walls. Then, as shown in Figure 4.30, allowance can be made for alignment variations.

Cross-Sectional Shape. Square posts or piles usually require only conventional framing techniques. With round posts or piles, however, the framing is somewhat more complicated, and it is generally best to frame the posts with a pair of beams, girders, or rafters—one on each side.

The roundness of wood posts is not a problem when using bolted or spiked connections as shown in Figure 4.31. The framing is then the same as for any other timber member.

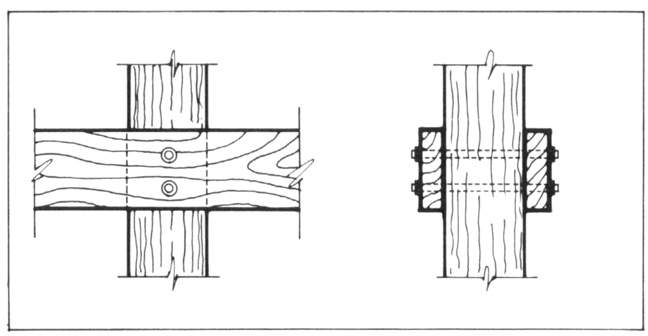


Figure 4.31. Bolted Connection to Round Pole

Another connection method is to eliminate the curve of the post or pile by dapping and then connecting with bolts, gusset plates, or other devices. As Figures 4.32 and 4.33 show, a dapped post will form seats that assist the beams in carrying vertical loads. Posts that are small in section, however, should not be dapped or they will be weakened. Generally, there should be a thickness of post or pile for the bolts to bear on equal to the total thickness of the floor beam. Two bolts should be used to connect beams to each post or pile.

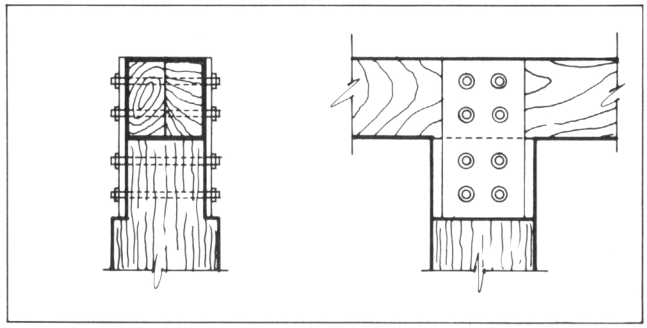


Figure 4.32. Dapped Gusset Plate Connection

Spike grid connections (Figure 4.34), standard in bridge and warehouse construction, are less common in residential practice. A single curved grid inserted between the post or pile and the beam substantially increases the strength of the bolted connection. With the curved side of the grid against the pole and over predrilled holes, a high-strength threaded rod is used to squeeze the two wood surfaces together, forcing the tooth of the spike grid into the grain of both members. The high-strength rod is then replaced with a conventional bolt of the proper size. A flat spiked grid is used to connect two flat surfaces, and a double curved spiked grid to connect two rounded surfaces.

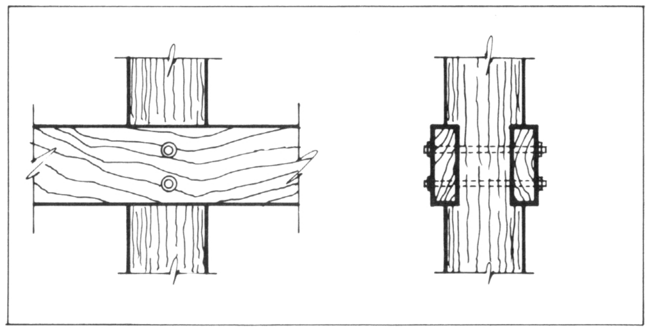


Figure 4.33. Dapped Pole Connection

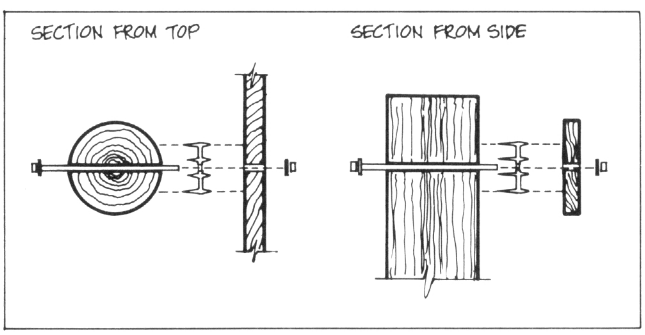


Figure 4.34. Spiked Grid

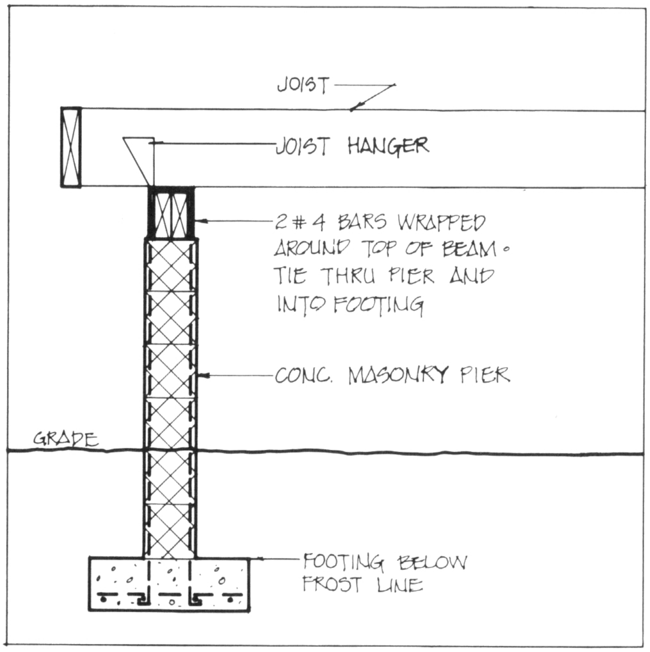


Figure 4.35. Concrete Masonry Unit Pier

Pier Foundations

Pier foundations are generally used for platform framing construction rather than pole framing construction.

Piers can be connected to floor beams in several ways. A pier's reinforcing steel rods can be extended from the pier and bent over or into the floor beam (Figure 4.35). A metal strap well-anchored in the pier can be bolted through the beam (Figure 4.36). Or (Figure 4.37) steel anchor bolts can be embedded in the pier and bolted through the beams with nuts and large-diameter washers.

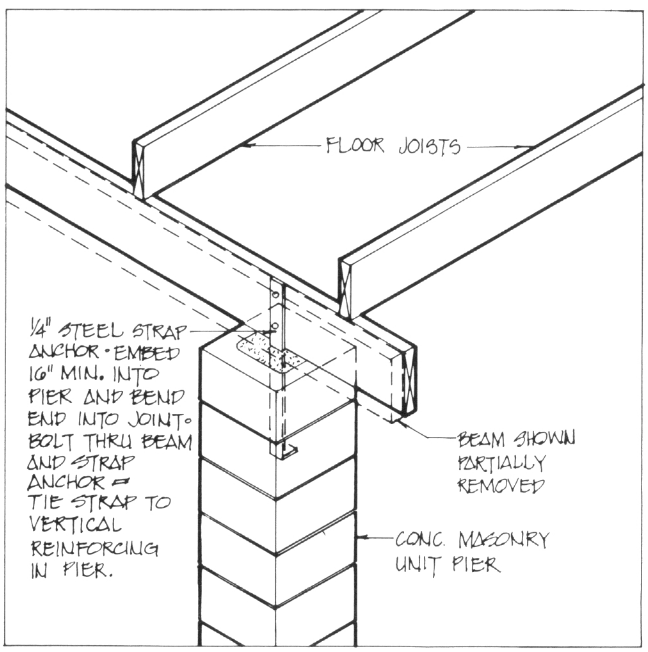


Figure 4.36. Masonry Pier— Strap Anchor

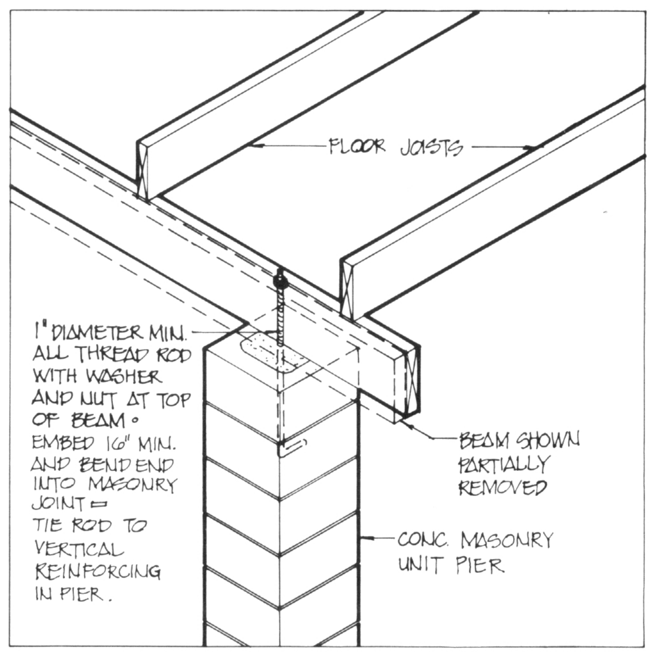


Figure 4.37. Masonry Pier—Bolt Through Beam

The bolts should be at least 1 inch in diameter and embedded at least 12 inches in concrete piers and 16 inches in masonry piers. If two floor beams abut on a pier, each must be anchored separately (Figure 4.38).

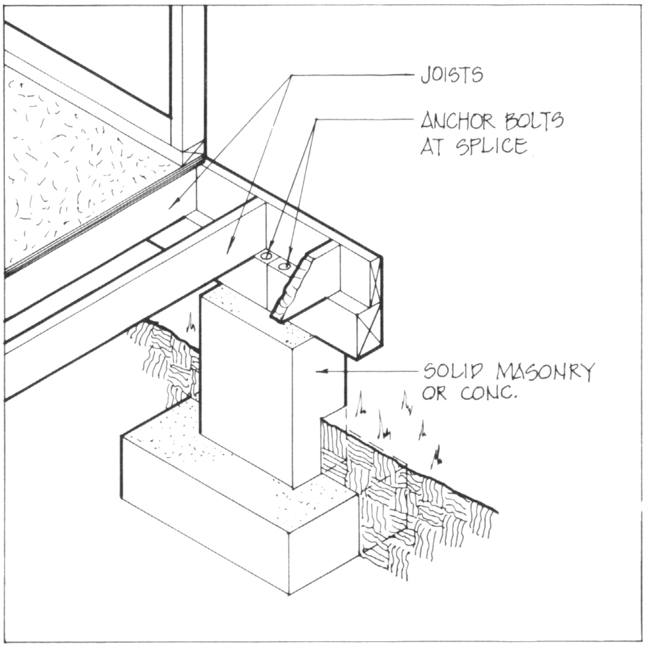


Figure 4.38. Beam Splice on Pier

FLOOR BEAMS

The floor beams attached to foundation elements in turn carry the floor joists and subflooring. Since floor beams that are as long as the width or length of residential structures are often difficult to find and hard to handle, it is common to use splices. Splices may occur in several places and need not always be located directly over supports.

Floor beams are often 4 x 10's or up to 6 x 12's, but they may be built up using standard framing lumber, such as two, three, or four 2 x 10's or 2 x 12's, spiked or bolted together. Where beams are built up using a good grade of lumber for the laminated members, the strength of the built-up beam can equal that of a solid member. All members of the built-up beam should be continuous between supports, because splices materially reduce strength. Built-up members should include only one splice at any one location. The ends and tops of built-up members should not be directly exposed to the weather.

The primary floor beams spanning between supports should span in the direction parallel to the flow of potential floodwater. This orientation allows the first transverse member perpendicular to flow to be the floor joist. Thus, in the case of an extreme flood the beams would not be subjected to the full force of floodwater along their more exposed surfaces. This also reduces the potential for floating debris to damage the structure, and places the lowest obstacle to flow above the floor beam.

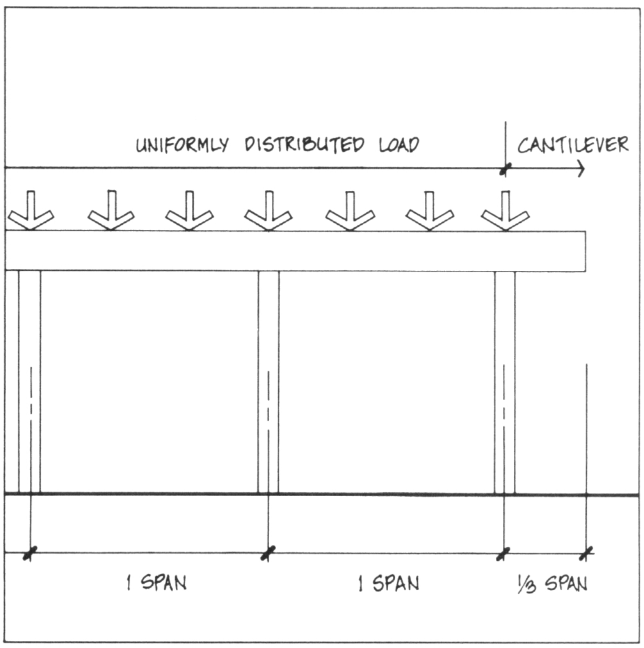


Figure 4.39. Floor Beam with Cantilever Overhang

CANTILEVERS

A cantilever is a projecting beam that extends beyond its support. The beam must be continuous (not spliced) over the last support prior to the cantilevered section, and depends on the vertical load applied for counteracting reactions (Figure 4.39). The practical limit recommended for a cantilever is normally one-third the length of the beam span prior to the cantilever.

The advantage of this method is that it can reduce the number of piles, poles, or piers required for a given area, as illustrated in Figure 4.40. Reducing the number of piles can result in potentially lower cost and fewer obstructions to the flow of floodwater and debris. Residences supported in this manner have the additional advantage of having the first row of piles set back, reducing the visual impact of elevating the structure. A cantilever design may use longer spans for the main floor beam and thus may require larger beams.

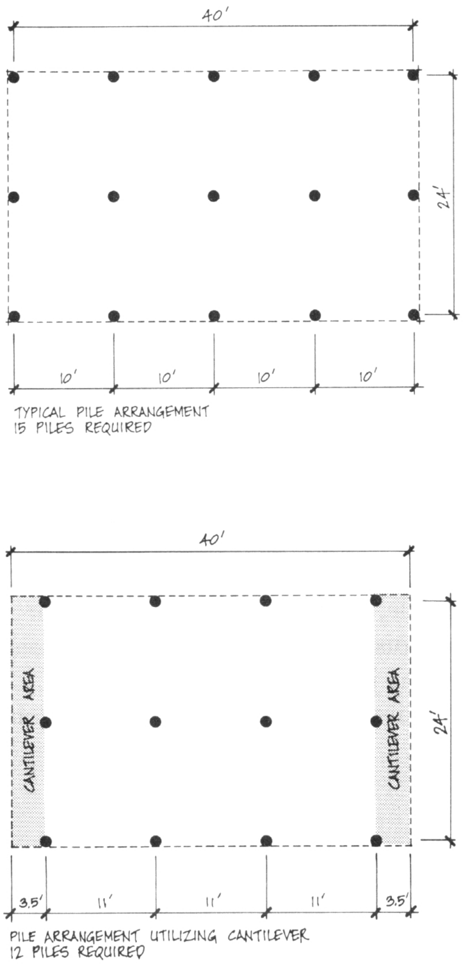


Figure 4.40. Cantilever Used to Reduce Number of Foundation Elements

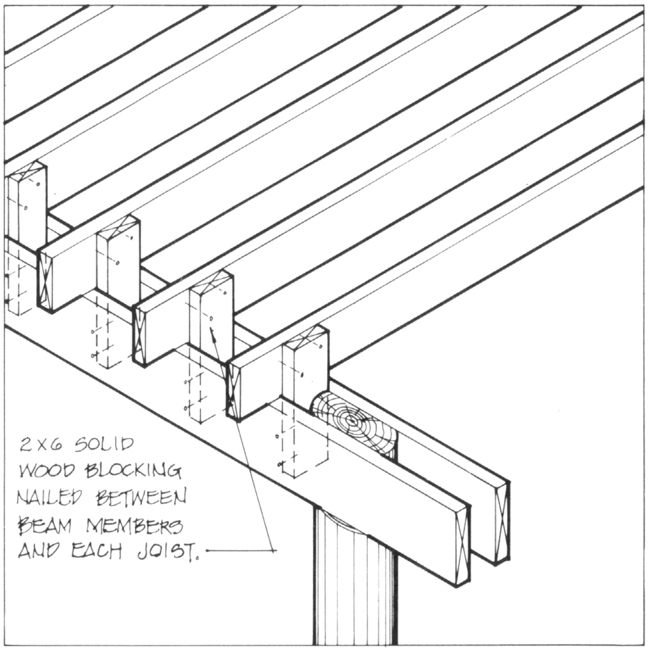


Figure 4.41. Wood Joist Anchors

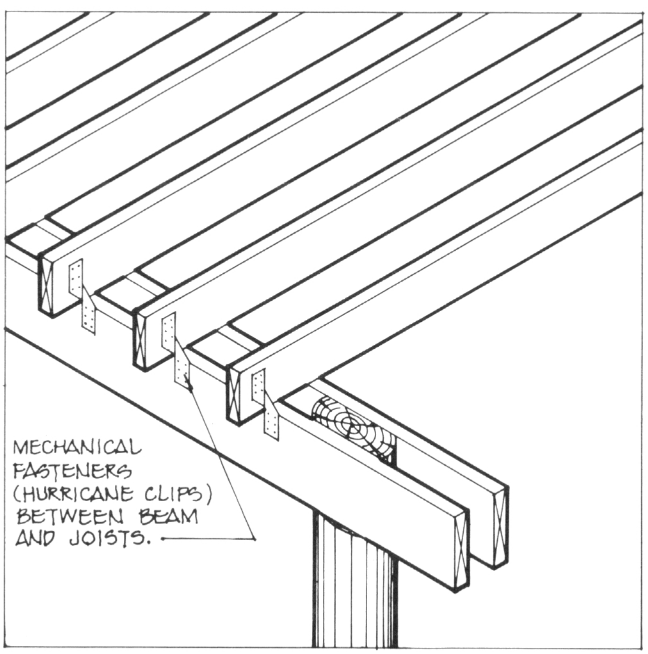


Figure 4.42. Metal Hurricane Clips

CONCRETE FLOORING SYSTEMS

Recently developed flooring systems using precast, prestressed concrete for floor beams, joists, and/or subflooring can often be useful in elevated structures. Construction and connection techniques for these systems are beyond the scope of this manual.

FLOOR-BEAM-TO-FLOOR-JOIST CONNECTIONS

A positive connection is also required beneath the first floor level between the floor joists and floor beams (Figure 4.41). Metal connectors now available provide strong positive connection (Figure 4.42). Metal straps can also be used provided proper nailing is done and a sufficient number of straps is installed. At the minimum, every other joist and wall stud should be anchored with a strap, and even more for more severe loads (Figure 4.43). A good wood connector has also been developed. The capacity of these connections depends directly on the number of nails and their individual capacity to resist loads transverse to their axis. Pullout resistance along the axis is not used; rather, the nails are placed at right angles (perpendicular) to the loads being transferred between the wood members. The number of nails counted in figuring the total connection capacity of a given joint is the lower number that exists on either side of the joint. For example, in the connection of a floor beam to a floor joist, if five nails are in the beam and four are in the joist, the capacity of the connection is limited by the four nails on the joist.

FLOOR JOISTS

Cross-bridging of all floor joists is recommended to stiffen the floor system. The elevation makes the floors (particularly the first floor) more accessible to uplift wind forces, as well as to the forces of moving water and floating debris. Effective cross-bridging requires:

- nominal 1 x 3's 8 feet on center maximum
- solid bridging same depth as joist 8 feet on center maximum.

SUBFLOORING

Two methods are commonly used for subfloor construction: nominal 1 x 4 or 1 x 6 boards placed diagonally over the floor joists (either tongue-and-groove or square-edge with expansion space between boards) and plywood subflooring used to create a floor diaphragm. When a plywood subfloor is planned, guidelines for thickness and methods of attachment in relation to joist spacing can be obtained from the *Plywood Construction Guide* published annually by the American Plywood Association. A well-constructed, firmly attached subfloor can be an important asset in resisting lateral forces.

Subflooring is typically nailed directly to the floor joists. Nailing with annular ring nails or deformed shank nails is recommended. These nails provide extra strength against pulling out when the floor system is exposed to loads other than gravity.

A system of nailing and adhesive application of plywood with tongue-and-groove joints along the long edges of the sheet avoids the need for blocking along these edges. This produces a more level floor and offers a stronger diaphragm action to resist horizontal flood forces.

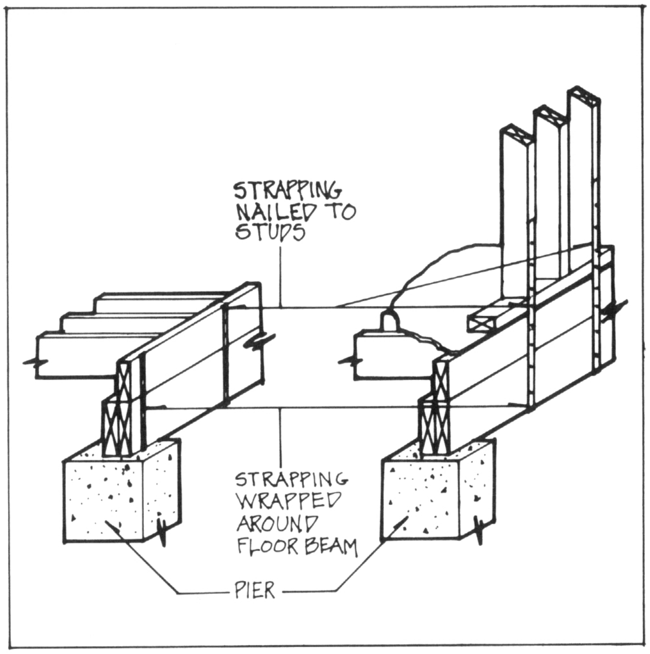


Figure 4.43. Metal Strapping

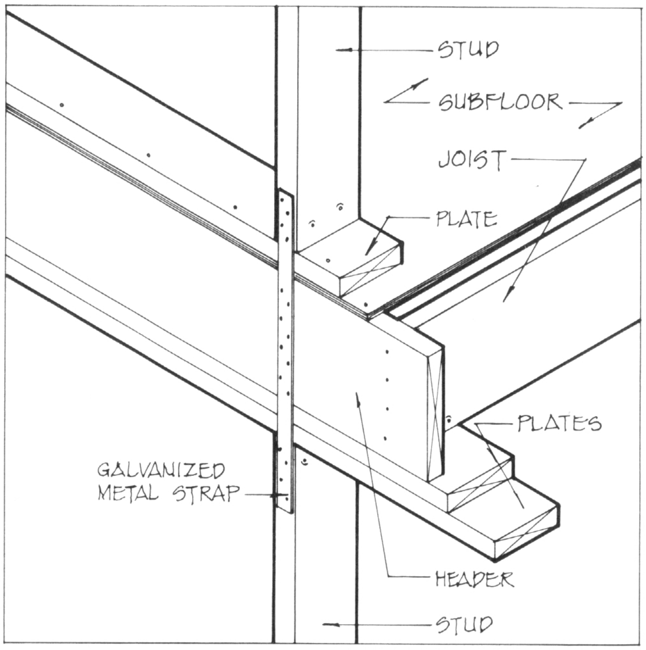


Figure 4.44. Stud-to-Stud Connections

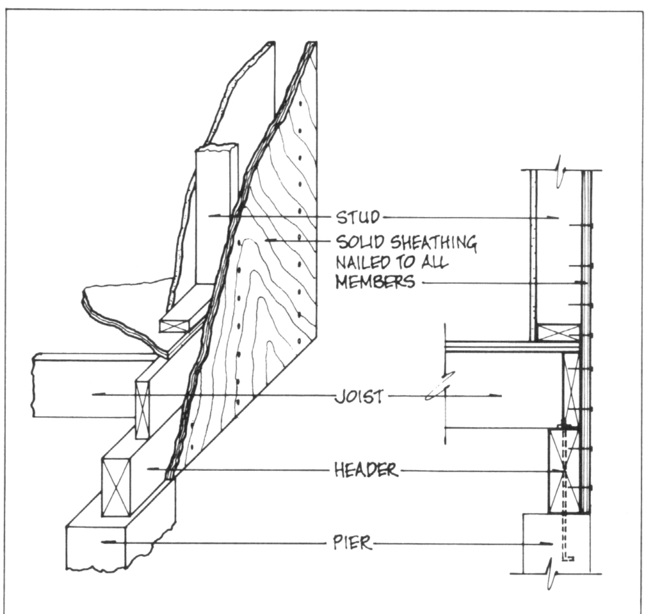


Figure 4.45. Plywood Anchorage

FLOOR-JOIST-TO-WALL CONNECTIONS

Elevated structures experience increased wind forces because wind speeds increase with elevation. Exterior walls are used as tension members to transfer wind uplift forces at the roof down to resistance provided by the foundation. It is usually necessary to use galvanized metal strap connections from alternate exterior wall studs to the floor joists or floor beams and from first floor studs to second floor studs (Figure 4.44). The capacity of these connections depends on the number of nails used. Manufacturers' brochures can be used to ascertain connectors' capacity and thus the spacing required.

WALL SHEATHING

Plywood is the most common sheathing in use for exterior walls (Figures 4.45 and 4.46). The major advantages of plywood are that it braces the wall framing to resist racking stresses and it forms a continuous tie from floor beam to top plate when properly installed.

Plywood used for sheathing structures elevated up to 10 feet above the ground should be exterior grade and not less than 1/2-inch thick. Nailing should be with sixpenny nails, spaced 6 inches along the edges of the panel and 12 inches on intermediate studs.

Structures elevated more than 10 feet should be sheathed with 3/4-inch exterior grade plywood, nailed with eightpenny nails, spaced as before. Deformed shank or annular ring nails and plywood with exterior glue are recommended.

WALL BRACING

Bracing vertical walls against racking is a common building practice, especially for weak materials such as some of the newer insulated sheathing. Wind forces and lateral forces from moving water are also significant factors in determining whether and to what extent to brace vertical walls.

Common wall bracing methods are a let-in diagonal wood brace, diagonal boards and plywood. A common method similar to the let-in diagonal brace is a light-gauge galvanized steel strap nailed diagonally to each stud at the outside corners and framed walls.

WALL-TO-ROOF CONNECTIONS

Probably the most critical structural connections for wind resistance are those between walls and the roof. For single-family residences, the roof structure is usually roof rafters of 2 x 10's or 2 x 12's or roof trusses built up of 2 x 4's or 2 x 6's. Whether rafters or trusses are used, they should be spaced at about 16 inches or 24 inches on center (16 inches is the more common spacing). Roof connections are critical because these connections are limited in number—at most they can occur at every roof rafter or truss.

A number of available galvanized metal connectors place the nails in an orientation to best resist uplift and lateral forces. Manufacturers' brochures provide the necessary design information.

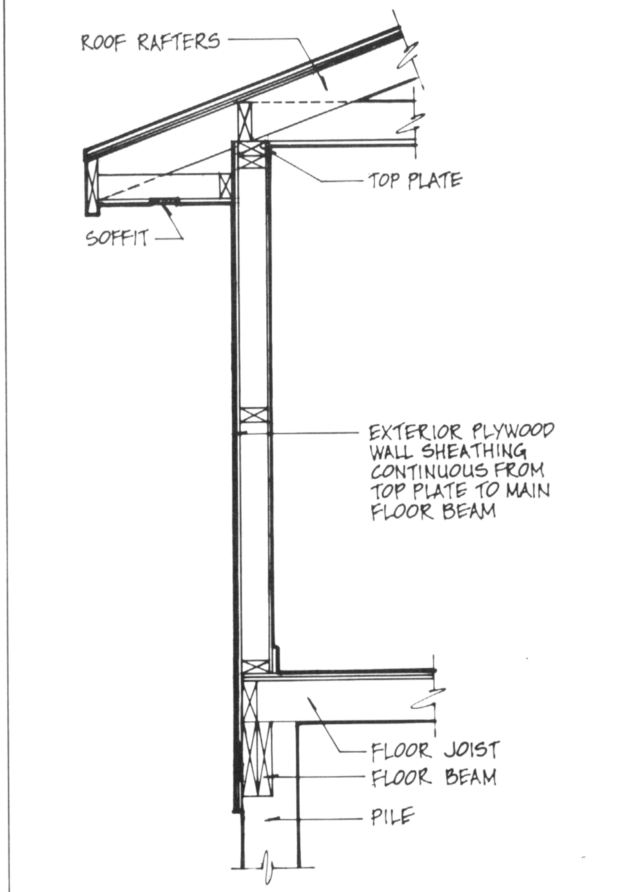


Figure 4.46. Wall Sheathing Tie from Roof to Ceiling

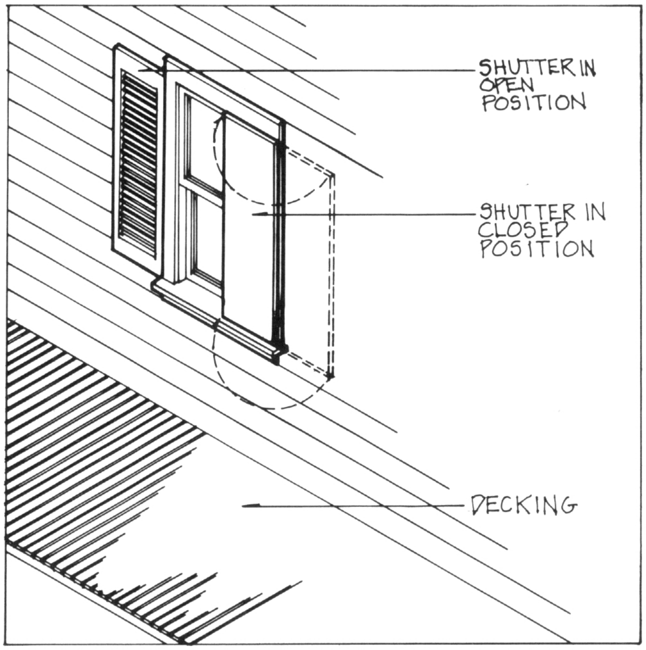


Figure 4.47. Shutters for Window Protection

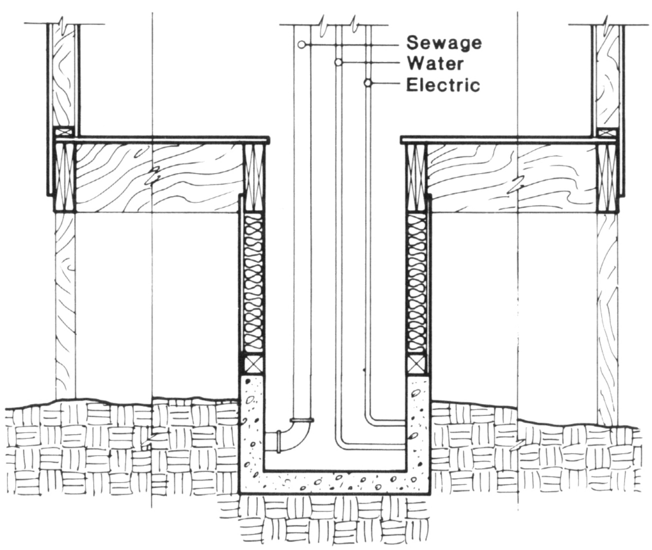


Figure 4.48. Protective Utility Shaft

GLASS PROTECTION

Even moderate storms or routine high winds can cause large losses of glass in buildings, particularly along a coast. Broken glass may allow rain and floodwaters and high winds to enter the structure. Water damage can ruin furnishings and eventually damage structural members. Wind allowed into an elevated structure increases the uplift load on the structure as it applies pressure to the ceiling and wall surfaces.

Exterior shutters can be used to protect glass. For small openings the traditional louvered shutter offers some protection. Additional protection is possible using 1/2-inch plywood attached to the back of the shutter, which will take the direct forces from the storm (Figure 4.47). This method allows coverage of fairly large areas of glass.

UTILITIES AND MECHANICAL EQUIPMENT

Structures in flood-prone areas are commonly served by combinations of electricity, water, sanitary sewer, gas (both natural and bottled), and telephone. Typical installations for these utilities expose them to potential damage from flooding and storm action. In the case of an elevated first floor, the connection from an underground utility line to the floor above further exposes the line to possible damage and/or contamination by flooding and storm action. Underground services are also susceptible to damage when erosion of the protective soil cover leaves them exposed during flooding.

Damage to utility lines can lead to contamination of drinking water, discharge of effluent from sewer lines, gas explosions, and fires and/or shock from damaged electrical systems.

The most vulnerable section of any underground utility line is the portion between the ground and the place it enters the elevated first floor. A minimum amount of protection can be obtained by locating these utility risers on the sides of interior elevated foundation elements opposite the direction of flood water. This can minimize damage from velocity water or floating debris. A more secure method is to place all utility lines coming from underground within a protective, floodproofed shaft under the elevated first floor (Figure 4.48).

If electrical and telephone lines are supplied from overhead service lines, they should be connected through the utility company's meter system above the expected reach of flood waters. However, this requirement is often in conflict with the power company's policy regarding the reading of meters and their location. If this is not possible, the connection should be made within a waterproof enclosure. All distribution panels or other major electrical equipment should also be located above expected flood waters. Branch circuit wiring should be fed from the first floor ceiling downward to minimize wiring on the first floor.

All mechanical equipment (furnaces, hot water heaters, air-conditioners, water softeners) should also be elevated above expected flood waters (Figure 4.49). An attic location, if available, would provide the equipment maximum safety. Heating and/or cooling systems using ductwork to carry tempered air should be provided with emergency openings at their lowest elevations and a minimum slope on horizontal duct runs in order to allow the system to drain in case it becomes submerged. Figure 4.50 illustrates some of these concepts.

Septic tanks should be floodproofed to ensure that flooding does not cause the tank to rise out of the ground if the tank is partially empty, as well as to ensure against discharge of effluent.

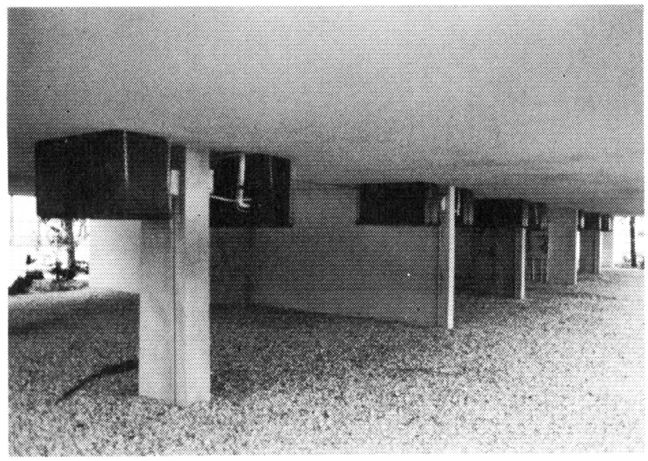


Figure 4.49. Elevated Condenser Units

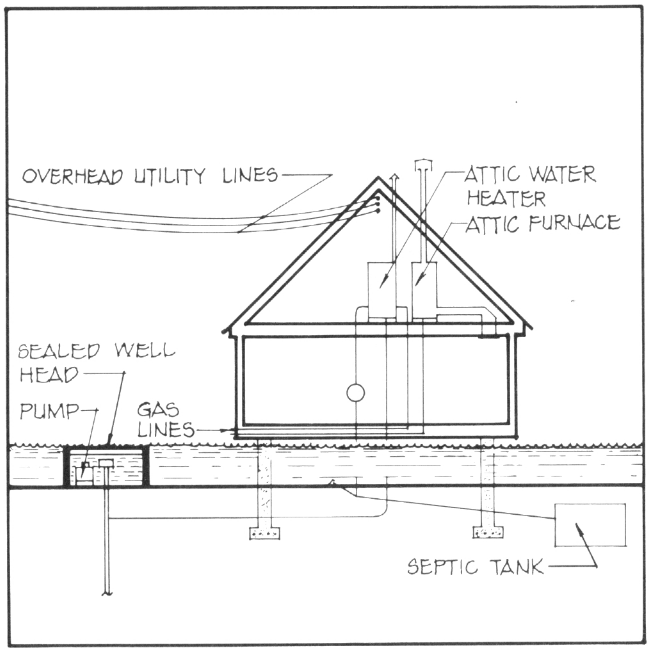


Figure 4.50. Locating Utilities

BUILDING MATERIALS

One way to increase the safety of building materials is to elevate the building higher than the minimum floodplain management requirements. Even then, however, flood waters may still reach building materials, so they should be protected.

A building elevated above grade has the underside of its floor area exposed to climatic and flood conditions, and will require special attention to protecting building materials. The climate and the desired appearance will determine whether the exposed underside of a floor should be sealed. Sealing exposed floors can protect subfloors and joists from the elements, improve insulation, and help conceal utilities.

The material used to enclose floor spaces should be resistant to water damage or inexpensive to replace if it is not resistant to damage. Exterior grade plywood treated with preservatives is water-resistant and can be effective. Gypsum products should not be used unless an acceptable level of performance is assured. Regardless of the material used, some provision must be made to allow water that may find its way into the floor sandwich during storms and flooding to drain out, and for the joist spaces to dry out.

Wood

Wood exposed to the elements should be protected by treatment with any one of a number of chemical preservatives to make the wood resistant to fungi attack, insects, bacteria, and rot. Connections should be designed so that water will not collect on or in them. They can be protected with protective flashing, by treating saw cuts and drill holes with preservatives, and by painting connections. The American Wood Preservers Institute, Tyson's International Building, 1945 Gallows Road, Vienna, Virginia 22180, can provide specific guidelines.

Steel

In riverine areas steel framing and foundation members exposed to the elements should be protected by galvanization or by painting with rust-retardant paints. The need for painting can be eliminated through the use of surface oxidizing steels (high strength low alloy).

In saltwater environments, exposed structural steel shapes, beams, pipes, channels, angles, etc., undergo very rapid corrosion, and their use should be avoided. Small connecting devices such as bolts, angles, bars, and straps should be hot-dipped galvanized after fabrication and coated with a protective paint after installation. Standard galvanized sheet metal joist hangers and other connecting devices deteriorate rapidly despite their galvanized coating and also require additional protective coatings. Small anchoring devices, nails, spikes, bolts, and lag screws should, whenever possible, be hot-dipped galvanized. With sheet metal clips and hangers, the special nails used should also be galvanized. Regular inspection, maintenance, and replacement of corroded metal parts is necessary when steel is used in the coastal environment. Steel rods used to reinforce concrete or masonry piles or piers require special precautions to prevent saltwater from reaching the steel through hairline cracks in concrete or through masonry joints. This is discussed below.

The American Iron and Steel Institute, 1000 Sixteenth Street, Washington, D.C. 20036, can provide specific guidelines.

Concrete and Masonry

The durability of reinforced concrete and masonry block can be improved by the use of chemical additives mixed with the concrete and mortar and by special treatments and coatings. Additives are numerous and vary from those that will prevent spalling due to freezing to those that will improve strength. Surface treatments and coatings, such as silicone and epoxy paints, can be used to reduce water absorption and penetration and to prevent damage by airborne pollutants. Guidance in the use of concrete and masonry can be obtained from the Portland Cement Association, Old Orchard Road, Skokie, Illinois 60076, and the National Concrete Masonry Association, P.O. Box 781, Herndon, Virginia 22070.

INSULATION

Like exposed walls of conventional structures, the exposed floor of elevated residences must be insulated against heat losses and heat gains. Depending on the climate, two factors should be considered. First, elevating a building will expose plumbing; such plumbing must be insulated against

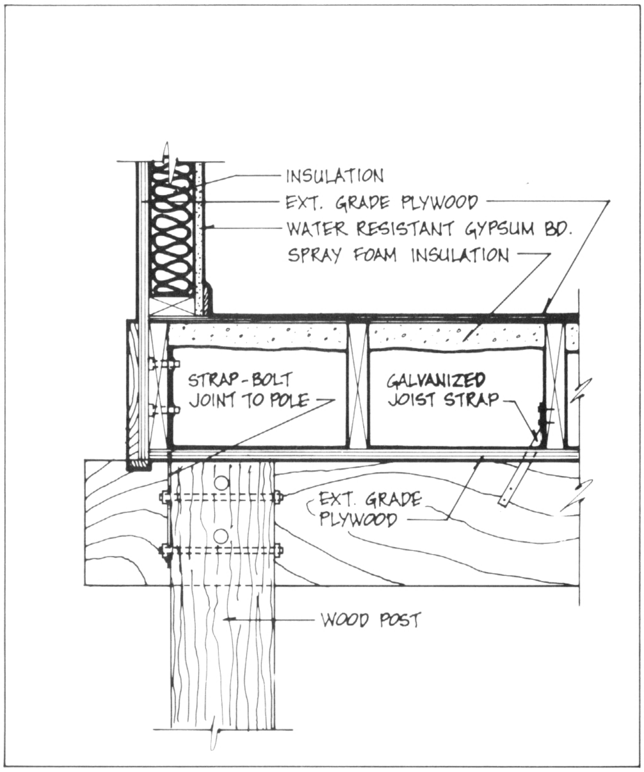


Figure 4.51. Insulated Floor Section, Wood Post Foundation

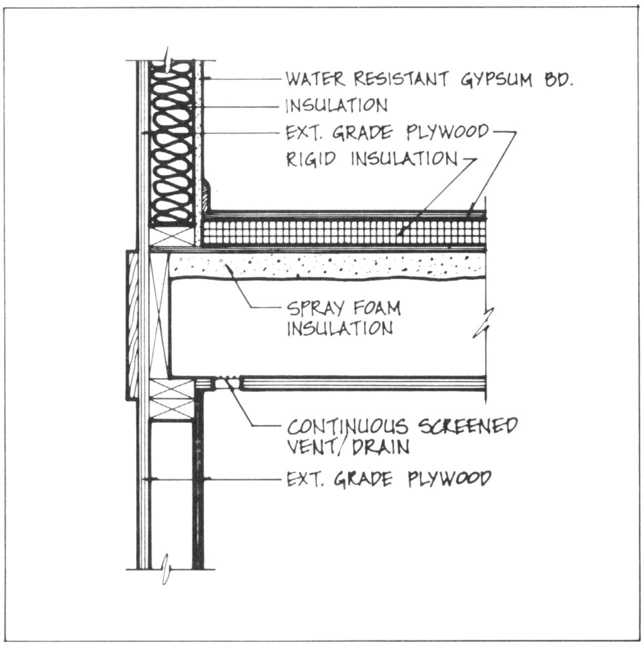


Figure 4.52. Insulated Floor Section, Foundation Wall

freezing. In extremely cold climates, heating cables may be necessary with the insulation. Second, insulated floor decks may be subject to floodwaters and should therefore have either impermeable, closed-pore insulation able to withstand water submersion or insulation that can be replaced economically (Figures 4.51 through 4.53).

BREAKAWAY WALLS

As indicated in *Design and Construction Manual for Residential Buildings in Coastal High Hazard Areas,* cited in the Preface, the area under an elevated structure in a V Zone must be free of obstructions or be constructed with breakaway walls (e.g., latticework) designed to collapse under stress without jeopardizing the structural support of the building (Figure 4.54). Loads from flood waters and waterborne debris are critical considerations in designing breakaway walls.

RETROFITTING EXISTING STRUCTURES

Existing residential structures in flood hazard areas can often be raised in-place to a higher elevation to reduce their susceptibility to flood damage. The principal consideration in raising existing structures is often the cost; generally, the technology exists to raise almost any structure, even multistory buildings, but the cost increases as the difficulty increases.

Residential structures have been satisfactorily raised up to nine feet. Aesthetics, intended use, needed flood elevation, and structural stability influence the height selected. Generally, the additional cost to raise a structure an additional foot or so is small compared to the initial set-up cost.

The new foundation for an existing structure should be selected and designed as discussed earlier.

Raising in-place is generally feasible for structures that are 1) accessible below the first floor for placement of jacks and beams, 2) light enough to be jacked with conventional house moving equipment, 3) small enough that they can be raised in one piece, and 4) strong enough to withstand the stress of the raising process.

Wood frame residential and light commercial structures with first floors above the ground (normally with an 18-inch crawl space beneath the first floor) are particularly suited for raising. Wood frame structures with basements below the first floor are also accessible and lightweight; however, raising the superstructure does not protect the basement, and the basement should be filled with a granular material to provide structural stability for the walls. Brick, brick veneer, and masonry structures, while heavier and more difficult to handle, can also be raised.

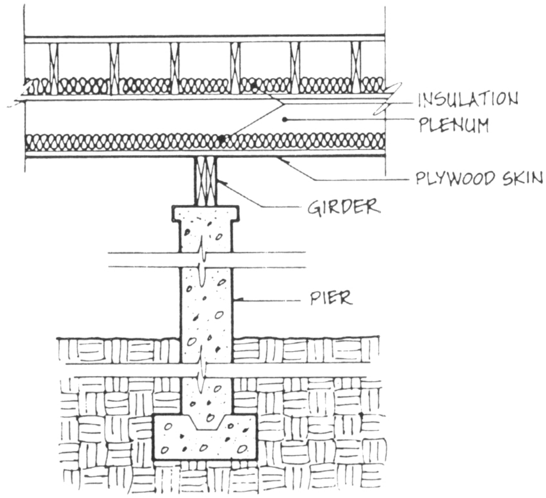


Figure 4.53. Double-Insulated Floor Plenum, Pier Foundation

Utility equipment located in a basement can often be moved to a higher room, such as an upstairs closet, or an attic. It is important to ensure that the closet or attic floor can support the weight of the equipment. If necessary, an elevated addition can be built to house a furnace, hot water heater, and other equipment formerly housed in a basement. Protecting utility equipment in this way can be useful even if the house itself cannot or need not be raised.

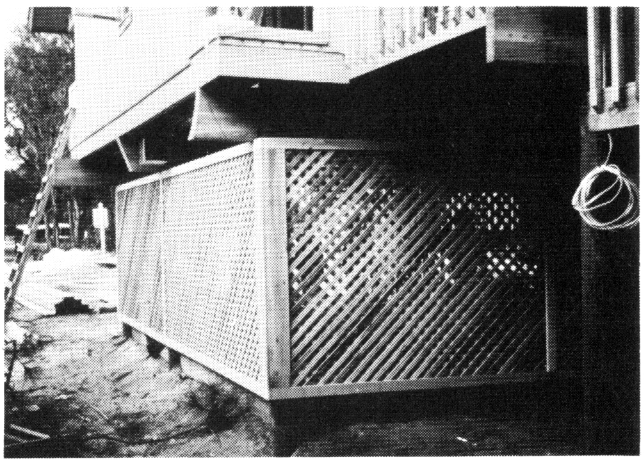


Figure 4.54. Breakaway Walls

Raising a structure usually involves the following steps:

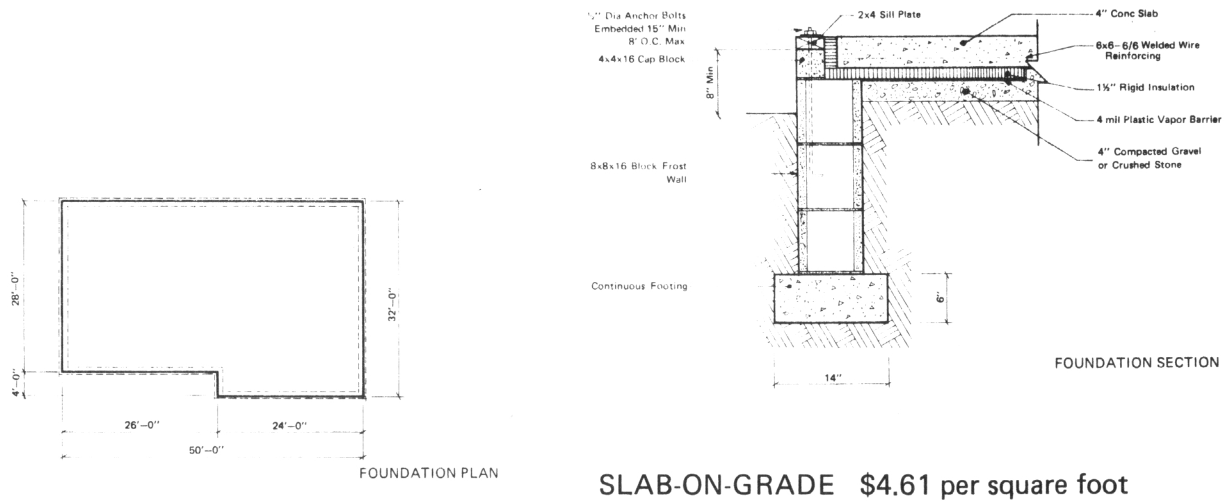
- Disconnect all plumbing, wiring, and utilities that cannot be raised with the structure.
- Place steel beams and hydraulic jacks beneath the structure and raise to desired elevation.
- Extend existing foundation walls and piers or construct new foundation.
- If a basement exists, remove water heater, furnace, etc., and fill basement with granular material to support basement walls.
- Lower the structure onto the extended or new foundation.
- Adjust walks, steps, ramps, plumbing, and utilities and regrade site as desired.
- Reconnect all plumbing, wiring, and utilities.
- Insulate exposed floor to reduce heat loss and protect plumbing, wiring, utilities and insulation from possible water damage.

COST ANALYSIS

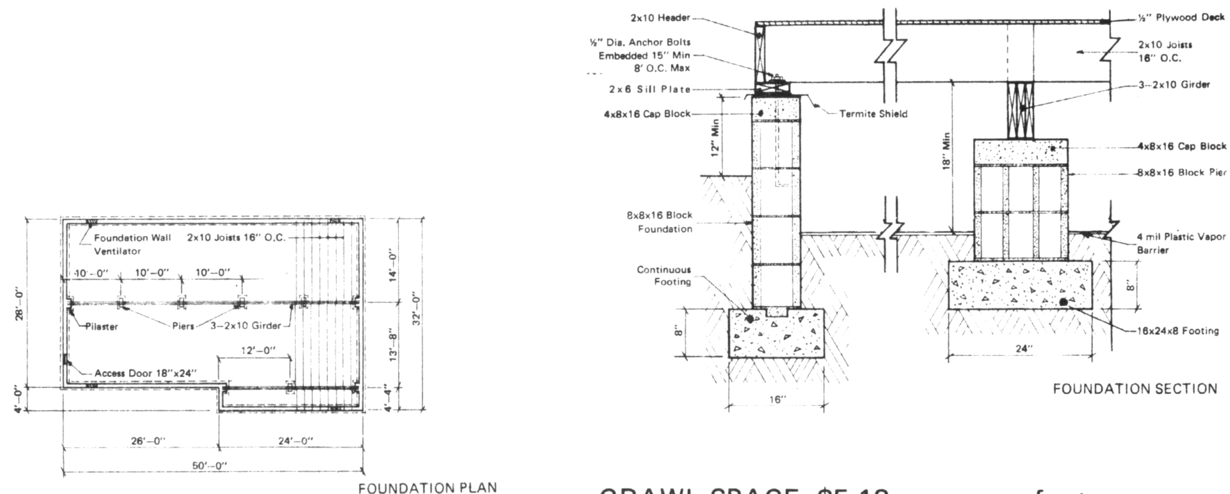
Once a community decides that the economic risk and environmental impact of developing floodplain land for residential use is acceptable, the dollar cost of that development must be evaluated. Two factors bear significantly on any such evaluation: first, the net cost of construction that meets the standards of the National Flood Insurance Program (NFIP) in light of the potential and unpredictable hazard of flooding and the losses that may ensue; second, the cost differentials between construction on elevated foundations and conventional building methods. (Note that standards adapted by local jurisdictions are often more stringent than the NFIP's.)

Repeated studies have shown that the savings that can be realized over the lifetime of a structure by building on a raised foundation are usually considerable when compared with the one-time increase in construction costs for an elevated foundation. This is largely because the the one-time foundation costs are generally only five or six percent of the total cost of a residential structure, while the flood insurance savings that can be achieved over the life of a structure by elevating it can be considerable.

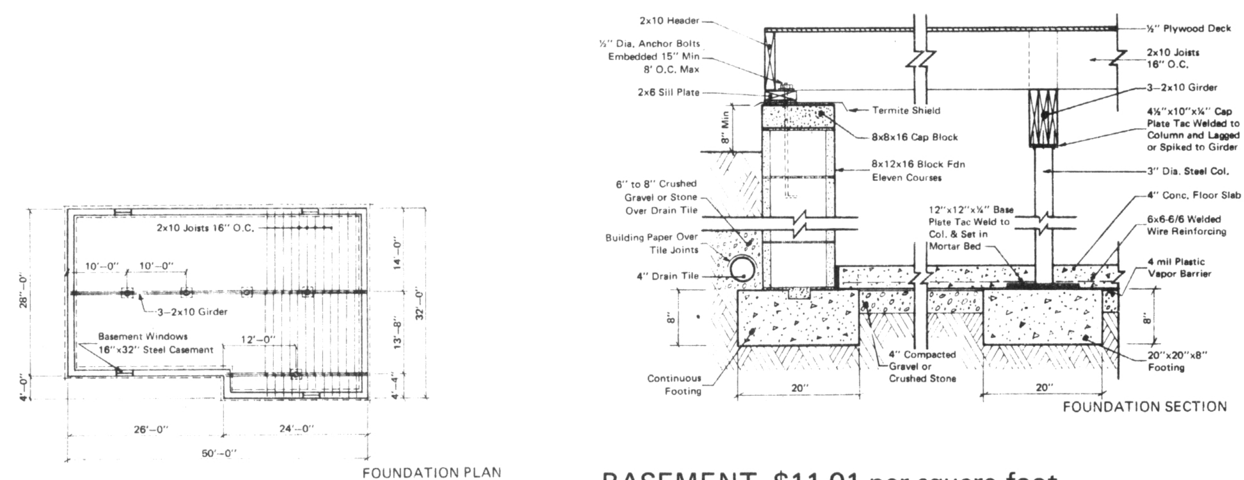
The economic cost to the individual of building a home in the floodplain consists of both flood damages that will occur and the costs of whatever measures are taken to mitigate such damages. The cost of flood damages to the homeowner may be partially shifted to federal, state, and local government through low-interest loans and tax deductions for losses incurred. In communities participating in the NFIP, the owner of a new home can purchase flood insurance. Essentially, flood insurance allows the homeowner to spread the flood risk to others facing the same hazards and, more importantly, permits one to pay for expected flood losses, which are unpredictable as to size and time of occurrence, in predictable annual payments. These are more manageable than unexpected flood losses, especially if more than one large flood happens to occur in a very short time.



SLAB-ON-GRADE $4.61 per square foot



CRAWL SPACE $5.13 per square foot



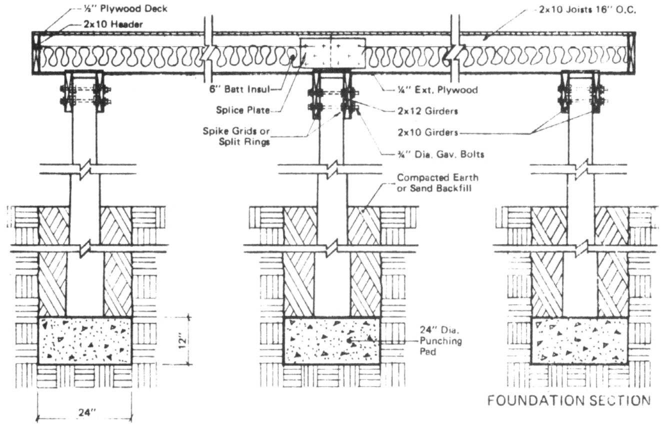
BASEMENT $11.01 per square foot

Figure 5.1. Conventional Foundations (Estimates are spring 1983.)

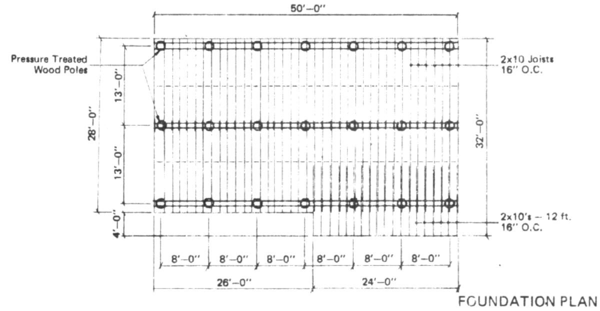
COST COMPARISON APPROACH

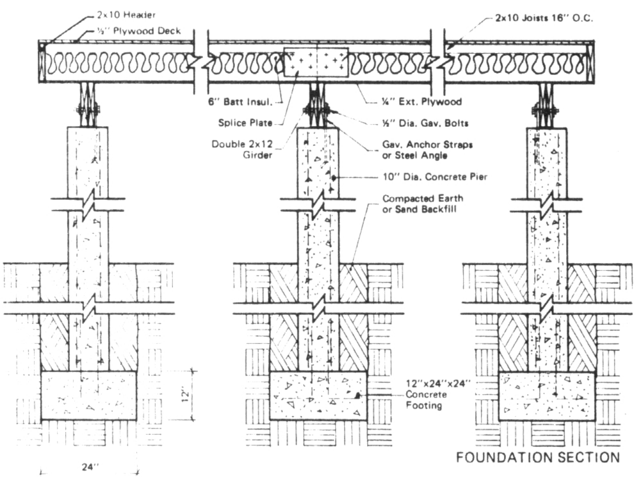
The costs of post, pile, and pier foundations are compared here to each other and to the costs of conventional slab, crawl space, and basement foundations. Cost data and estimating forms are provided for roughly estimating one's particular foundation costs.

1. *Slab-on-grade, crawl space, and basement foundations* were selected as three of the most common types of residential foundations, and detailed drawings of them were prepared (Figure 5.1). Detailed drawings were also prepared for the three most typical elevation foundation types. These are post, pile, and pier foundations (Figure 5.2). (Regarding use of earth fill, see below.)

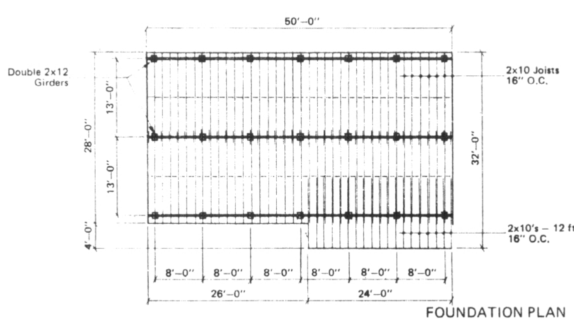


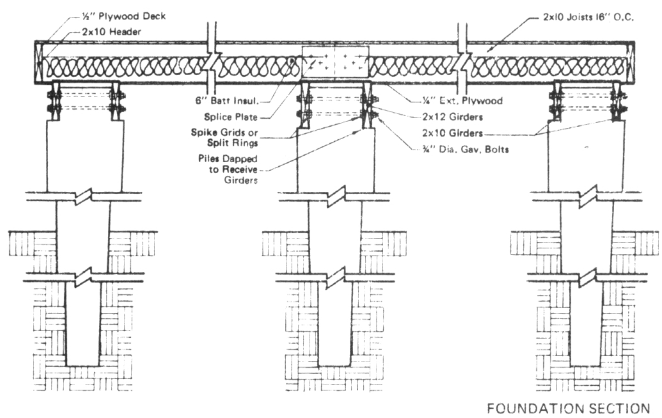
WOOD POST $6.96 per square foot





CONCRETE PIER $7.08 per square foot





WOOD PILE $6.58 per square foot

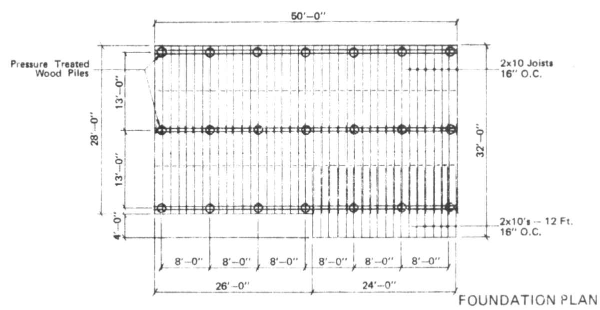


Figure 5.2. Elevated Foundations (Estimates are spring 1983.)